REVIEW OF POLLUTANT LOSSES FROM SOLID MANURES STORED IN TEMPORARY FIELD HEAPS

Report for Defra Project: WT1006

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Submitted to:

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EXECUTIVE SUMMARY

The present Nitrate Vulnerable Zones-Action Programme (NVZ-AP) contains the following rules which control the location of field heaps to minimise the risks of pollutant losses to the environment, viz:

- Field heaps must not be located:
    - within 10m of a surface water or land drain;
    - within 50m of a spring, well or borehole;
    - on land likely to become waterlogged;
    - on land likely to flood; or
    - in any single position for more than 12 successive months (and there must be a two year gap before returning to the same site).
- Poultry manure without bedding/litter which is stored in a field heap must be covered with an impermeable sheet.

The Commission have indicated that, as part of discussions for the next NVZ-AP, they would like to see further *evidence* on the pollution risks associated with the temporary field storage of solid manures. They would 'prefer' all solid manures to be stored on an impermeable base or, as a minimum, for less than 12 months of temporary storage.

The findings of this report have shown that leachates from solid manure heaps can contain *elevated concentrations* of multiple pollutants (e.g. ammonium-nitrogen (N), nitrate-N, phosphorus-P, biochemical oxygen demand-BOD and microbial pathogens), which could cause detrimental effects if they reached surface water bodies in an undiluted form. Leachate concentrations of most pollutants (e.g. ammonium-N, BOD and E.coli) peaked at the start of the storage period (i.e. within 2 months of leachate generation), however, elevated P concentrations were measured throughout the whole storage period.

Covering poultry manure field heaps (with an impermeable sheet) was shown to be an effective method of decreasing leachate volumes and pollutant losses.

In practice, pollutants in leachate infiltrating soil underneath a field heap (and in run-off from the heaps) are likely to be either retained in the soil or diluted with 'uncontaminated' water from the rest of the field. Thus, pollutant concentrations will be reduced provided that there are sufficient 'barriers' between the field heap and the receiving water.

It is recommended that further research is undertaken to: (i) evaluate the effect of 'real-world' field heap manure storage on surface water quality and soil nutrient status; (ii) gather sufficient evidence to establish if 10 metres is a 'safe' distance between field heaps and receiving waters/drains and; (iii) establish the extent of leachate volume decreases that could be achieved through covering farmyard manure (FYM) heaps.

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1 INTRODUCTION

Approximately 90 million tonnes (fresh weight) of livestock manures are applied annually to agricultural land in the UK (Williams *et al*., 2000). Of these manures, 52% (47 million tonnes) are handled as slurries (cattle and pig) and the remainder (43 million tonnes) as solid manures (straw-based farmyard manure - FYM and poultry manure). Around 70% of FYM (cattle and pig) and 50% of poultry manures are stored prior to land spreading in England and Wales (Misselbrook *et al*., 2008), enabling them to be spread at times of the year when the risks of soil compaction and water pollution are low, and when the manures are is likely to be of most benefit to crops. Arable rotations of winter sown crops (e.g. winter wheat/barley, oilseed rape) that predominate in England and Wales leave only a month or so for applying solid manures to stubbles in August/September. It is generally impractical to apply FYM to growing arable crops at other times of the year, without causing smothering and/or creating soil compaction. Opportunities for more flexible applications timings occur with spring-sown arable crops and grassland (including re-seeding).

The temporary field storage of solid manures is an important farm practice which, if not permitted, would have a significant impact on farming operations and would incur additional storage costs. Defra project WA0656 (Implications of Potential Measures to Control Pathogens Associated with Livestock Manure Management) estimated that if all solid manures in England and Wales (around 30 million tonnes per year) had to be stored on an impermeable base, this would cost £845 million in capital expenditure. Notably, the EU Commission would 'prefer' all solid manures to be stored on an impermeable base or, as a minimum, for a shorter field storage period than 12 months.

Storing solid manures on an impermeable base prevents leachate seepage and the accumulation of high concentrations of nutrients in soil below the field heap, which may subsequently be lost to surface and ground waters. Leachate from solid manure field heaps may also contain microbial pathogens and have a high biochemical oxygen demand (BOD - a measure of the oxygen used by microorganisms to decompose organic material), which will restrict the oxygen available to other aquatic organisms (e.g. fish, invertebrates etc.).

The Commission have indicated that, as part of discussions on the next Nitrate Vulnerable Zones–Action Programme (NVZ-AP) they would like to see further evidence on the pollution risk associated with the temporary field storage of solid manures. The current NVZ-AP (SI, 2008) contains the following rules which control the location of field heaps to minimise the risk of pollutant losses to the environment, viz:

- Field heaps must not be located:
  - within 10m of a surface water or land drain (other than a sealed impermeable pipe);
  - within 50m of a spring, well or borehole;
  - on land likely to become waterlogged;
  - on land likely to flood; or
  - in any single position for more than 12 successive months (and there must be a two year gap before returning to the same site).
- Poultry manure without bedding/litter which is stored in a field heap must be covered with an impermeable sheet.

Additionally, Defra/EA (2008) guidance states that solid manures may only be stored in field heaps if they are solid enough to be stacked in a free-standing heap and do not give rise to free drainage from within the stacked material. Also, there is a need to identify the location of field heap sites on the farm risk map.

2 OBJECTIVES

The objectives of this study were to:

- Review the current evidence base to establish concentrations of the main potential pollutants (nitrate, ammonium, phosphorus, organic matter/BOD and microbial pathogens) from solid manure heaps and identify the factors that influence the nature and quantity of leachate produced.
- Assess leachate losses of potential pollutants from field heaps located in accordance with (a) the current NVZ-AP rules, and (b) more stringent rules (e.g. shorter storage periods, located further away from watercourses).
- Review rules and advice in other EU Member States to minimise pollutant losses from temporary solid manure field heaps.
- Identify knowledge gaps that require further investigation.
- Provide recommendations on whether to retain or amend the current NVZ-AP controls on the siting of field heaps, supported by robust evidence and clear arguments that could be presented to the EU Commission and stakeholders.

3 LITERATURE REVIEW

3.1 Rules and advice in other Member States

The storage of solid manure in field heaps allows farmers to spread them when the risks of soil compaction and water pollution are low, and when the manures are most likely to be of benefit to crops. This practice is common in the UK, with an estimated 69% of cattle/pig FYM and 50% of poultry manures stored before land spreading, with the majority (>80%) stored in field heaps (Misselbrook *et al*., 2008). We were unable to identify any information on how much solid manure was stored in temporary field heaps elsewhere in the EU or any rules relating to field heaps in other Member States, other than in Northern Ireland (EHSNI, 2007) and Southern Ireland (DAF, 2008).

Northern Ireland. FYM and poultry litter (defined as a mixture of bedding material and poultry excreta with a dry matter content not less than 55%) may be stored in a compact heap in the field where land application will take place, but for no longer than 180 days. It must not be stored in the same location of the field year after year. Field heaps must not be stored within:

- 50 m of lakes; or
- 20 m of any other waterway, including open areas of water, open field drains or any drain which has been backfilled to the surface with permeable material such as stone/aggregate; or
- 50 m of a borehole, spring or well; or
- 250 m of a borehole used for a public water supply; or
- 50 m of exposed cavernous or karstified limestone features (such as swallowholes and collapse features).

Poultry (broiler/turkey) litter must be covered with an impermeable membrane within 24 hours of placement in the field. The field heap storage of layer manure is not permitted in Northern Ireland.

Southern Ireland. FYM must not be stored in a field during the prohibited spreading period for FYM (1st November – 12th, 15th or 31st January, depending on the Zone of country). It can be stored in a field during the spreading season, but it must be stored in a compact heap. FYM cannot be stored within the following buffer zones:

- 250 m of any water supply source providing 100m^3 or more of water per day, or serving 500 or more people
- 250 m of any water supply source providing 10m^3 or more of water per day, or serving 50 or more people
- 50 m of any other water supply for human consumption
- 20 m of a lake shoreline
- 50 m of exposed cavernous or karstified limestone features (such as swallow holes and collapse features)
- 10 m of any surface watercourse where the slope towards the watercourse exceeds 10%

- 10 m of any other watercourse
- 10 m of any open drain or where the area of land adjacent to the watercourse is a narrow parcel of land less than 50 metres wide and not more than 1 hectare in area

There are no specified rules on the storage of poultry manures in field heaps in Southern Ireland.

There are some important differences between the rules for solid manure field heap storage in Northern Ireland, Southern Ireland and Britain:

- In Southern Ireland, the buffer distance between field heaps and water supply sources providing over 10 m^3/day or serving over 50 people is 250 m, compared with 50 m from any spring, well or borehole in Britain and Northern Ireland.
- Specified distances between field heaps and certain surface waters are greater in Northern Ireland (50 m from lakes; 20 m from other waterways/drains) and Southern Ireland (20 m from lakes) than in Britain (10m from a surface water/drain).
- In Northern Ireland, poultry *litter* (i.e. from broilers/turkeys) stored in field heaps must be covered with an impermeable membrane, whereas in Britain poultry litter field heaps do not require covering. However, field stored layer manures must be covered with an impermeable membrane in Britain. There are no specified rules in Southern Ireland on storage of poultry manures in field heaps. These differences (most probably) reflect the relative importance of the laying hen and broiler industries in the three countries.
- In Northern Ireland, field heaps must not be stored within 20 m of open field drains or any drain which has been backfilled to the surface with permeable material (such as stone/aggregate) and in Southern Ireland within 10 m of an open drain, whereas in Britain field heaps may not be stored within 10 m of any land drain (other than a sealed impermeable pipe).
- In Northern Ireland, field heap storage must be for no longer than 6 months duration and in Southern Ireland (as a result of the closed period for FYM) must be for no longer than *c*.9 months duration, whereas in Britain field heap storage may be for up to 12 months duration.

3.2 Cattle FYM

Sommer and Dahl (1999) measured leaching losses during the storage (197 days) of cattle FYM from three pilot-scale heaps (3.7 m long, 1.9 m wide and 1.3 m high) on a sealed surface in Denmark; the manure was either stored conventionally, compressed or mixed once after thirty days. Leachate volumes were 0.6 m^3/t from the compressed heap and 1 m^3/t from both the mixed and conventionally stored heaps. The ammonium-N concentration in the leachate was <3 mg/l, whilst the nitrate-N concentration was less than the limit of detection (P concentrations were not reported). The authors calculated that N and P leachate losses were equivalent to *c*.0.4% and *c*.0.8% of the initial heap contents, respectively.

Sommer (2001) also measured leaching losses during the storage of four pilot-scale cattle FYM heaps (with the same dimensions as above) to assess the potential for reducing leaching (and gaseous) losses by compaction, mixing and covering the manure heaps. As in their previous study (Sommer and Dahl, 1999), P losses were low (in the range 1.7–2.4% of initial heap contents from all treatments). Potassium leachate losses were higher (due to its high solubility) and ranged from 8% of initial heap K contents from the covered heap treatment to 16% from the mixed heap treatment. N losses were in the range 2.3–3.4% of initial heap total N contents. Ammonium-N concentrations in the leachates were in the range 0.02–0.43 mg/l and nitrate-N concentrations in the range 0.1–0.3 mg/l. Leachate nutrient concentrations decreased throughout the storage period, with the highest concentrations of both ammonium-N and nitrate-N measured in the first leachate samples (measurement date not reported). Sommer (2001) suggested that the relatively low losses were most probably due to the high C:N ratio of the FYM (20:1) that may have enhanced immobilisation and thereby reduced nitrification and denitrification. Kirchmann (1985) previously showed that an increase in manure C:N ratio significantly reduced N loss during manure storage.

Parkinson *et al*. (2004) investigated N and P losses during the composting of cattle FYM in England. The experiment measured leachate and gaseous losses (ammonia and nitrous oxide) from turned (one or three turns) and static solid manure heaps (10 - 12 m^3) stored on a gently sloping concrete base. Leachate ammonium-N concentrations were significantly lower from the static heaps than from the turned heaps, and fell progressively over the storage period of *c*.4 months (Table 1). In general, there was an inverse relationship between leachate ammonium-N and nitrate-N concentrations, and a trend towards increasing nitrate-N concentrations as the storage period progressed. Soluble P (measured as molybdate reactive P - MRP) concentrations in the leachate tended to remain constant from the static heaps throughout the storage period (in the range 64–183 mg/l), but increased following turning on the turned heaps.

Table 1: Leachate ammonium-N, nitrate-N and MRP concentrations (mg/l) from static and turned cattle FYM heaps (Parkinson *et al*., 2004).

Treatment	Ammonium-N				Nitrate-N				MRP	
	Day 1	Day 19	Day 48*	Day 120*	Day 1	Day 19	Day 48*	Day 120*	Day 1	Day 19
Static	65	15	*c*.5	*c*.10	0.9	4.4	*c*.1	*c*.4	64	183
Turned once	143	57	*c*.25	*c*.10	1.5	4.4	*c*.7	*c*.7	89	197
Turned 3 times	84	193	*c*.50	*c*.10	1.1	6.1	*c*.16	*c*.17	70	247

Data presented for Experiment 1 (stored January-April).
*Ammonium-N and nitrate-N concentrations on days 48 and 120 were derived from graphs

Chadwick (2005) also measured leaching losses from cattle FYM heaps (3 replicates, 5-8 tonnes of manure per heap) stored in south-west England for a period of between 90 and 109 days. FYM was either stored conventionally in uncovered heaps or compacted and covered, to assess the effect of the two treatments on gaseous emissions and leachate losses. Total N losses in leachate were 0.14 kg N from the conventional heaps and 0.22 kg N from the compacted and covered heaps, equivalent to *c*.0.5% and *c*.0.8% of the initial total N content of the heaps at the start of storage.

Notably, Oenema *et al.* (2007) reported that few studies had quantified nutrient losses from animal manure storage systems, via leaching and run-off. However, the available information suggested that water-borne N losses from solid manure in unsealed heaps was likely to be *c.*2% of the initial N content of the manure when covered and *c.*5% when uncovered, although there was a high degree of uncertainty associated with these estimates.

3.3 Poultry manure

Ritter *et al*. (1994) investigated leachate N losses from broiler litter heaps in the Delmarva Peninsula of the United States, an area characterised by sandy soils and a high ground water table. In this region, poultry growers typically remove poultry litter (including bedding) from the poultry house once a year and remove crusted manure after each flock. In most cases, the manure is stockpiled in uncovered field heaps prior to land spreading. Leachate losses were monitored from 6 manure heaps (3 covered and 3 uncovered) for 11 months. Ammonium-N concentrations in leachates were low ranging from <0.05 to 1.15 mg/l. In contrast, nitrate-N concentrations were above 10 mg/l and increased over the manure storage period. There were no significant differences (P>0.05) in leachate nitrate-N concentrations between the covered and uncovered manures. Soil samples taken from below the manure heaps showed that the total mass of ammonium-N and nitrate-N in the soil (on a hectare equivalent basis) ranged from 1,080 to 10,280 kg/ha, which was reported to be "much higher than in fertilised fields".

Also in the US, Felton *et al*. (2003) investigated the effects of covering poultry litter heaps (with tarpaulins) on nutrient availability and movement. Covering the heaps was found to reduce the nitrate concentration of soil water beneath the heaps, regardless of soil type.

3.4 Pig FYM

We were unable to identify any assessments of leachate losses from pig FYM in the published literature, which is most probably a reflection of the vast majority of western Europe and US pig production systems being slurry based.

4 OVERVIEW OF EXPERIMENTAL EVIDENCE BASE IN ENGLAND

Leachate production volumes and nutrient losses during solid manure storage were measured from pig and cattle FYM and poultry manures stored for a range of time periods, and from contrasting management practices (e.g. covered or turned heaps) in previous Defra-funded studies in England, where the focus was on measuring gaseous N emissions of ammonia and nitrous oxide. Typically, these studies were carried out on manure heaps stored on a concrete or impermeable membrane base (to facilitate leachate collection). Experimental data from the following Defra-funded projects was collated and reviewed in this project.

4.1 Defra project WA0632: Ammonia fluxes within solid and liquid manure management systems

The overall objective of this project was to quantify and compare ammonia losses from solid and liquid cattle and pig manure management systems. At North Wyke Research (Devon), cattle FYM was stored from January to October 1999 and from January to October 2000, with 2 replicate heaps (*c*.15 tonnes fresh weight) in each of two the study years. The solid manure stores had 5 m diameter hardcore bases, with a 1° slope, surrounded by straw bales and lined with polythene sheeting. Leachate was collected in buried tanks adjacent to the lowest point. At ADAS Terrington (Norfolk), pig FYM was stored in heaps (*c*.1.7 tonnes fresh weight) of a similar design. There were 2 replicates from each of two summer (FYM stored from August 1998 to February 1999 and from August 1999 to January 2000) and two winter (FYM stored from February to October 1998 and from February to September 1999) housing periods.

Leachate volumes were measured monthly and representative samples analysed for dry matter, total N, ammonium-N and nitrate-N concentrations to quantify leachate N losses from the heaps (Chadwick *et al*., 2002).

4.2 Defra Project WA0651: Ammonia fluxes within broiler litter and layer manure management systems

The overall objective of this project was to quantify and compare ammonia losses from contrasting broiler litter and layer manure management systems, in order to improve understanding of ammonia fluxes through different poultry manure management systems.

The effect of different layer manure removal frequencies (daily or weekly) on ammonia emissions from a belt-scraped house was studied at ADAS Gleadthorpe (Nottinghamshire) in 1998-1999 (Nicholson *et al*., 2004). Using layer manures from contrasting removal frequencies, four manure heaps were created (each 6-8 tonnes) which remained in place for 10-16 months. Total N, ammonium-N, nitrate-N and BOD concentrations were measured in leachates from each treatment (leachate volumes were not measured).

4.3 Defra project WA0712: Management techniques to minimise ammonia emissions during storage and land spreading of poultry manures

The overall objective this project was to quantify ammonia emissions from contrasting poultry manure storage (uncovered and covered with 1000 gauge polythene sheet) practices, and following land spreading of the stored manures. The experiment was set up in December 1998 at ADAS Gleadthorpe (Nottinghamshire), using three types of poultry manure collected from commercial units: broiler litter (from birds bedded on wood shavings at the end of a 7 week production cycle), deep pit layer manure (from below a building housing caged hens where the manure had accumulated for *c.*12 months) and belt-scraped layer manure (from a heap adjacent to the building from where it had been removed and stored for *c.*7 days). There were two replicates of each storage treatment (i.e. 12 heaps in total) arranged in a randomised block design, with the manures stored in circular field heaps of 6 m diameter (covering a surface area of 28 m^2) and *c.*2 m height, sited on an impermeable polythene sheet. Each heap contained *c.*20 tonnes (fresh weight) of manure. The volume of leachate generated was measured and samples (collected fortnightly during the storage period) were analysed for total N, ammonium-N, nitrate-N, total P, total K and dry matter concentrations.

4.4 Defra Project WA0716: Management techniques to minimise ammonia emissions from solid manures (REAMS)

The overall aim of this project was to quantify the effects of contrasting storage methods on ammonia emissions from solid manure heaps and following land application of the manures. To compare solid manure storage methods, experiments were set up at ADAS Gleadthorpe (Nottinghamshire) and North Wyke Research (Devon). At ADAS Gleadthorpe, gaseous ammonia losses and leachate volumes were measured from pig FYM stored for 6-month (April to October 2000) and 12-month periods (April 2002 to April 2003), and from broiler litter stored for a 6-month period (April to November 2001); Sagoo *et al.* (2004). At North Wyke Research, the same measurements were made from cattle FYM stored for 4-month (May to September 2000) and 11-month periods (April 2002 to March 2003), and from broiler litter stored for a 6-month period (October 2001 to April 2002).

The experiments measured leaching losses from the following treatments:

- conventional (i.e. open air heaps - designed to be similar to a 'typical' on-farm field heap);
- sheeted (covered with plastic sheeting to help prevent rainfall ingress);
- turned (heap turned twice during conventional open air storage);
- additional straw (50% more straw added during house to increase the C:N ratio – pig and cattle FYM, and 100% more straw added during housing - cattle FYM only);
- A-shaped manure heaps (broiler litter only);
- roofed heaps (broiler litter only).

At both sites, the manure heaps were *c.*15 m^3 in volume and constructed on concrete pads equipped with leachate collection facilities. Each storage treatment was replicated three times and heap layouts were arranged in a randomised block design. The volume of leachate produced during storage was measured and samples were analysed for total N, ammonium-N, nitrate-N, total P, total potassium (K) and BOD concentrations.

4.5 Defra Project WQ0111: Faecal indicator organism losses from farming systems (*FIO-FARM*)

The overall objective of this project was to establish the processes and pathways of faecal indicator organism (FIO) losses from farming systems to surface waters, and to identify the relative contribution of different potential FIO loss routes to the overall FIO burden of surface waters. In order to assess the relative contribution of FIO losses from solid manure heaps, pig and cattle FYM was stored for *c*.3 months at ADAS Gleadthorpe (Nottinghamshire). Heaps (approximately 3.6m x 3.6m in surface area and containing *c*.5 tonnes of manure) were constructed on concrete pads equipped with leachate collection facilities, with each treatment replicated three times. Manure leachate volumes were collected daily for the first fortnight and thereafter following rainfall events, and analysed for *E.coli* most probable numbers.

5 LEACHATE VOLUMES

Leachate volumes were measured from different sized solid manure heaps and over different time periods in the Defra-funded experiments, making it difficult to directly compare the results. In order to facilitate comparison, leachate volumes were converted (where appropriate) from litres per heap per measurement period to millimetres per m^2 of manure heap surface area per day ($mm/m^2/d$).

5.1 Experimental results

Leachate loss volumes from cattle FYM stored at North Wyke for 11 months (in both 1999 and 2000) were *c*.0.03 $mm/m^2/d$ (Defra project WA0632), Table 2. In contrast, leachate volumes from cattle FYM stored in conventional heaps at North Wyke for 4 months (in year 2000) and 11 months (in 2002/3) were much higher at 0.24 and 0.31 $mm/m^2/d$, respectively (Defra project WA0716), Table 2. The extra straw and sheeted treatments (in Defra project WA0716) at North Wyke had no consistent effect on daily leachate volumes. Leachate loss volumes were in the range 6-45% of rainfall volumes over the storage period.

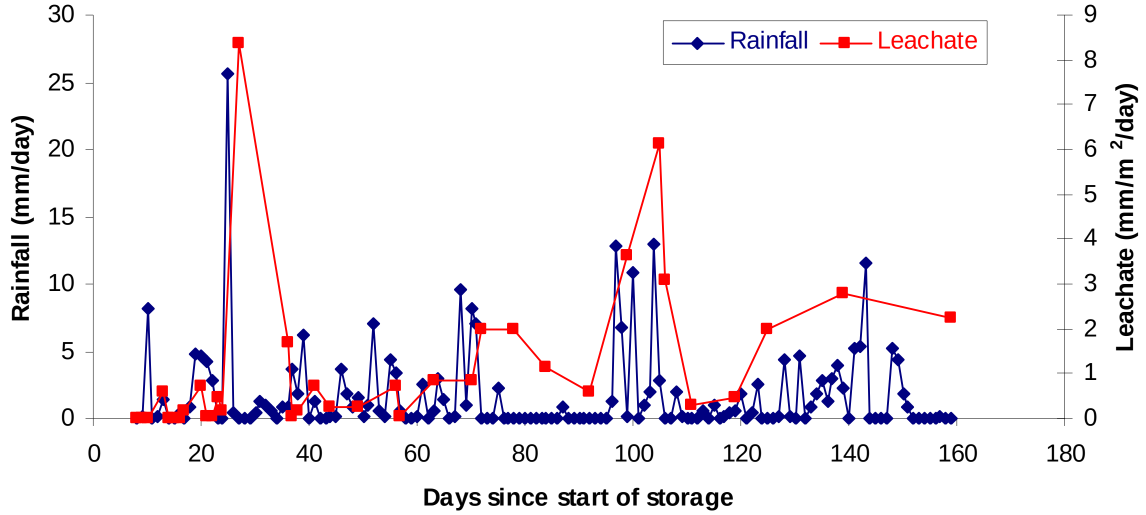
Table 2: Leachate volumes from cattle FYM heaps.

Defra project	Site	Storage period and treatment	Mean daily leachate ($mm/m^2/d$)	Leaching loss (% rainfall volume)
WA0632	North Wyke	10 months storage		
		Jan-Oct 1999	0.03	35
		Jan-Oct 2000	0.03	25
WA0716	North Wyke	4 months storage		
		Conventional	0.24	12
		50% extra straw	0.32	16
		100% extra straw	0.23	12
		Sheeted+	0.41	21
WA0716	North Wyke	11 months storage		
		Conventional	0.31	10
		50% extra straw	0.20	6
		100% extra straw	0.20	6
		Sheeted+	0.39	12
WQ0111	ADAS Gleadthorpe	*3 months storage*	1.1	45
		5 months storage	0.3	17

+ Rainfall running directly off the plastic sheet was also collected as part of measured leachate volumes

Data from ADAS Gleadthorpe (Defra project WQ0111), showed that high volume rainfall events were responsible for peaks in the volume of leachate produced from cattle FYM heaps (Figure 1).

(a)



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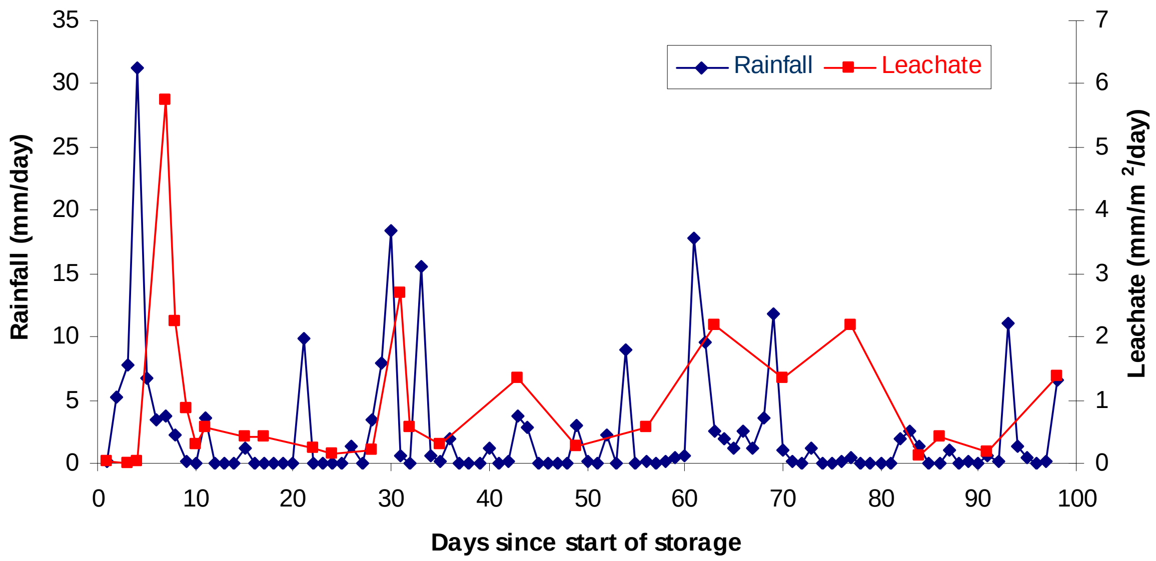


Figure 1: Leachate loss patterns (mm/m^2/day) from cattle FYM stored at ADAS Gleadthorpe for (a) 3 months and (b) 5 months, with rainfall (mm/day) for the corresponding periods (Defra project WQ0111)

For pig FYM stored in conventional heaps (Defra projects WA0716 and WQ0111), mean daily leachate losses ranged from 0.58 to 1.27 mm/m^2/d at ADAS Gleadthorpe, with leachate loss volumes in the range 34-69% of rainfall volumes over the storage period (Table 3). There was an indication that turning pig FYM (and broiler litter) reduced the volume of leachate generated compared with conventional heap storage (Tables 3 and 4, and Figure 2), probably because turning increased heap temperatures and hence increased evaporation losses. The extra straw and sheeted treatments at ADAS Gleadthorpe had no consistent effect on daily leachate volumes.

Table 3: Leachate volumes from pig FYM heaps.

Defra project	Site	Storage period and treatment	Mean daily leachate (mm/m^2/d)	Leaching loss (% rainfall volume)
WA0632	ADAS Terrington	6-9 months storage		
		Feb-Oct 1998	na	32
		Feb-Sep 1999	na	45
		Aug 1998-Feb 1999	na	55
		Aug 1999-Jan 2000	na	36
WA0716	ADAS Gleadthorpe	6 months storage		
		Conventional	1.27	52
		Sheeted$^+$	1.90	75
		Extra straw	0.84	34
		Turned	0.71	29
WA0716	ADAS Gleadthorpe	12 months storage		
		Conventional	0.58	34
		Sheeted$^+$	1.02	56
		Extra straw	0.81	45
		Turned	0.54	30
WQ0111	ADAS Gleadthorpe	*2 months storage*	0.9	65
		4 months storage	1.1	69

na = not available
$^+$ Rainfall running directly off the plastic sheet was also collected as part of measured leachate volumes.

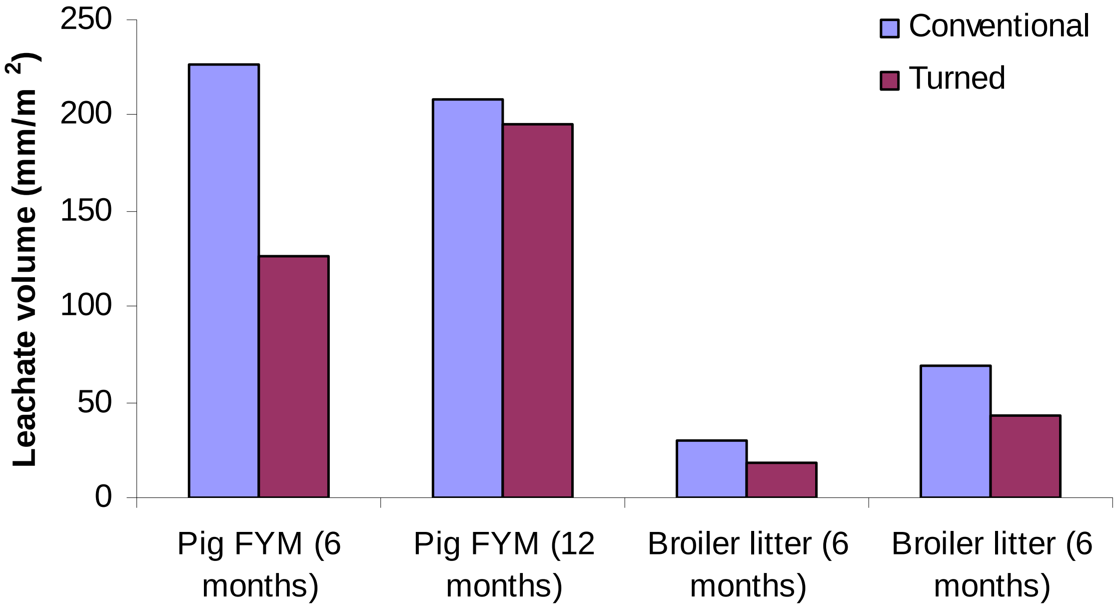
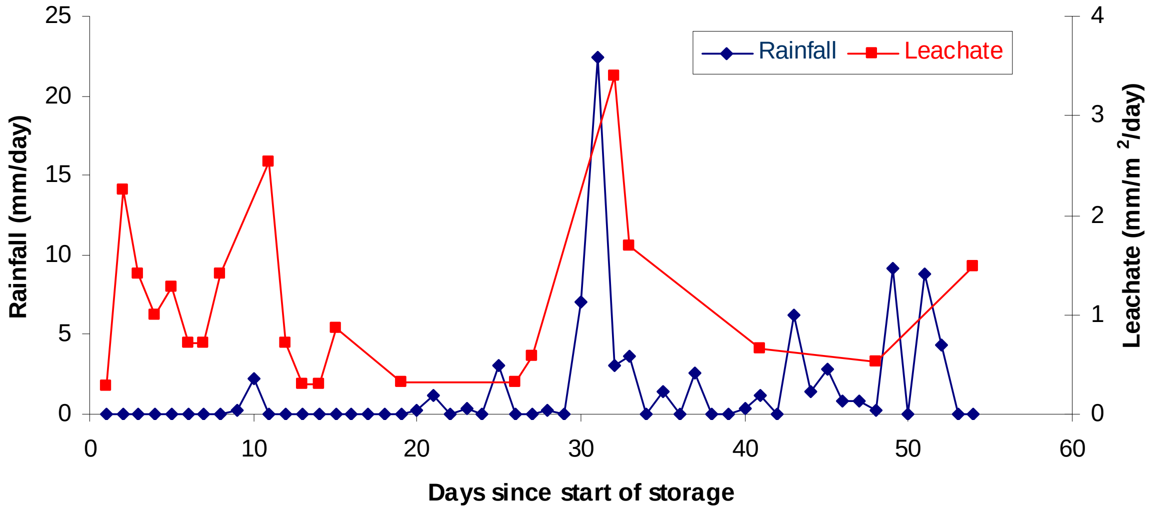


Figure 2. Leachate volumes generated from conventional and turned pig FYM and broiler litter heaps (Defra project WA0716)

As with cattle FYM, data from ADAS Gleadthorpe (Defra project WQ0111) indicated that high volume rainfall events were responsible for peaks in the volume of leachate produced from pig FYM heaps (Figure 3).

At ADAS Gleadthorpe (Defra project WA0716), there were no leaching losses from roofed broiler litter heaps that were stored in a large walled building which excluded rainfall (Table 4). Greater leachate volumes from the sheeted heaps (P<0.05) were a result of rainwater running directly off the plastic sheet and down the inside of the manure containment pad into the leachate collection system. Mean leachate volumes from the conventional broiler litter heaps at North Wyke were equivalent to 12% of rainfall volumes over the storage period and were similar to those from the conventional broiler litter heaps at Gleadthorpe (7% of rainfall volumes over the storage period).

(a)



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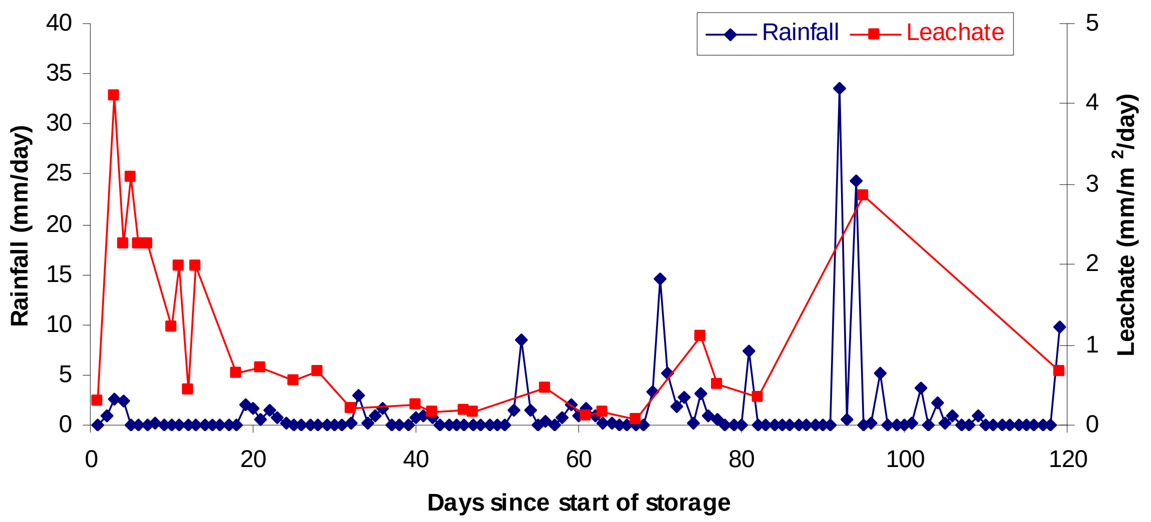


Figure 3: Leachate loss patterns (mm/m^2/day) from pig FYM stored at ADAS Gleadthorpe for (a) 2 months and (b) 4 months, with rainfall (mm/day) for the corresponding periods (Defra project WQ0111)

Covering poultry manure heaps (Defra project WA0712) was shown to be an effective method of reducing leachate volumes, with mean leachate volumes from the uncovered heaps equivalent to *c.*4% of total rainfall volumes over the storage period compared with *c.*0.6% from the covered heaps (Table 4 and Figure 4); a mean reduction of *c.*85%.

Table 4: Leachate volumes from poultry manure heaps.

Defra project	**Site (poultry manure type)**	**Storage time and treatment**	**Mean daily leachate ($mm/m^2/d$)**	**Leaching loss (% rainfall volume)**
WA0716	ADAS Gleadthorpe (Broiler litter)	6 months storage		
		Conventional	0.16	7
		A-shaped	0.20	10
		Sheeted+	0.56	27
		Turned	0.10	5
		Roofed	0	0
WA0716	North Wyke (broiler litter)	6 months storage		
		Conventional	0.45	12
		Sheeted+	0.42	11
		Roofed++	0.17	5
		Turned	0.27	7
WA0712	ADAS Gleadthorpe (broiler litter)	12 months storage		
		Uncovered	0.04	2
		Covered	0.01	0.5
WA0712	ADAS Gleadthorpe (layer manure)	12 months storage		
		Belt-scraped uncovered	0.11	5.6
		Belt-scraped covered	0.01	0.6
		Deep pit uncovered	0.09	4.3
		Deep pit covered	0.01	0.6

+ Rainfall running directly off the plastic sheet was also collected as part of measured leachate volumes

++ Includes rain water ingress through the side of the building

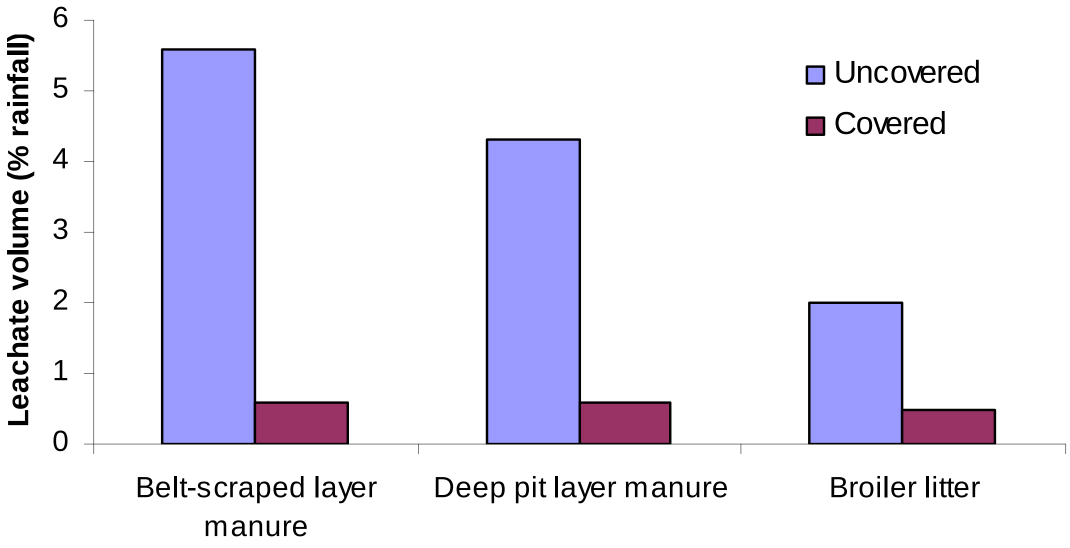


Figure 4. Leachate volumes generated from uncovered and covered poultry manure heaps (Defra project WA0712)

The lower leachate volumes from the broiler litter (Table 4) compared with the pig FYM (Table 3) heaps, most probably reflected the higher dry matter content of the broiler litters (range 46-54%) compared with the pig FYMs (range 24-36%) at the start of storage, which enabled more rainfall to be 'absorbed' by the broiler litter heaps.

5.2 Summary

Utilising data from the conventionally stored poultry manure/pig FYM (i.e. uncovered heap) experiments collated above, it was possible to establish a relationship ($P<0.01$) between the initial dry matter content of the manures and the overall volume of leachate generated during the storage period, expressed as a percentage of rainfall volumes over the storage period (Figure 5). For the higher dry matter poultry manures, the volume of leachate produced was lower, probably because the drier manure heaps were able to 'absorb' more of the rainfall (which may also have subsequently evaporated) rather than allowing it to contribute to leachate volumes. For poultry manures (with a dry matter content of more than about 35%), the leachate volume generated was <15% of total rainfall volumes.

Lower leachate volumes were measured from covered (*c*.85%) than from uncovered poultry manure heaps (Defra project WA0712, Figure 4), indicating that covering poultry manure heaps is an effective method for reducing leachate losses. Moreover, covering layer manure field heaps is a requirement of the NVZ-AP in England (SI, 2008) to decrease water pollution risks, as well as reducing odour and fly nuisance.

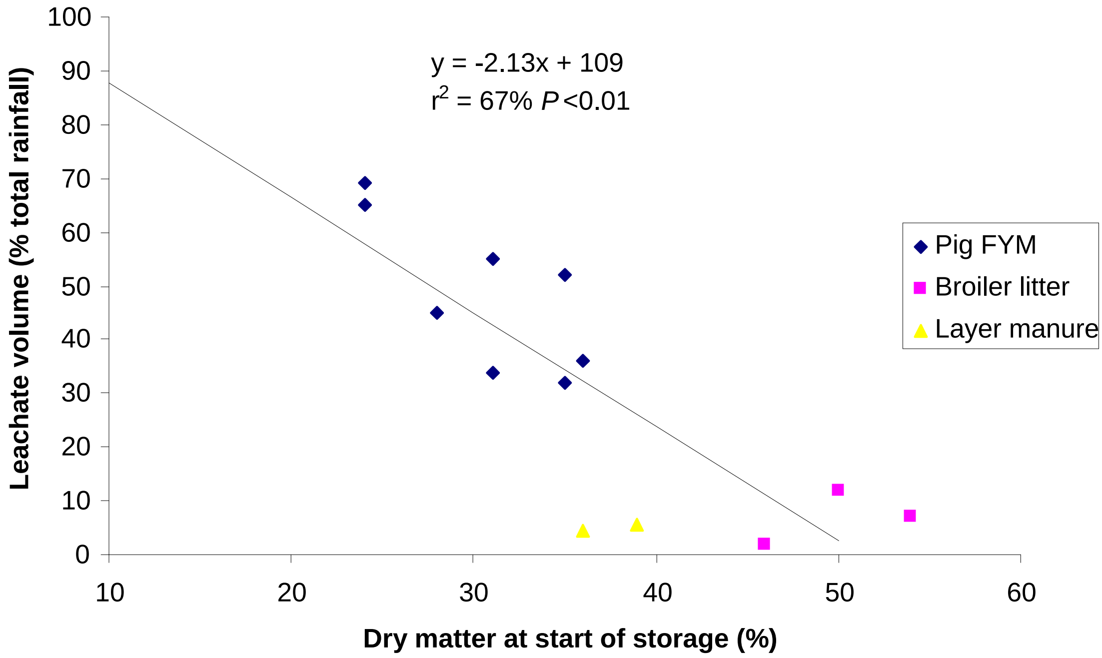


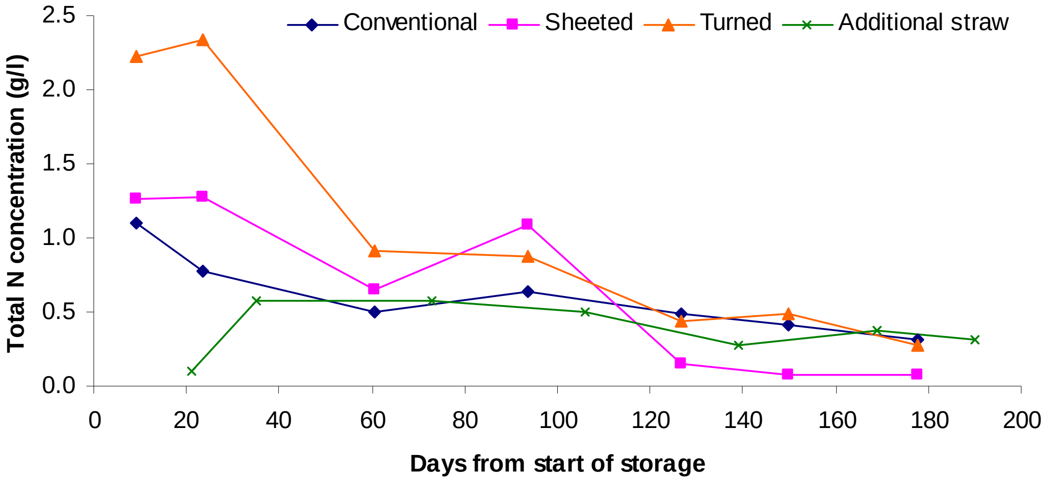
Figure 5: Relationship between the initial dry matter content of poultry/pig manures (%) and the overall volume of leachate generated during the storage period (% total rainfall). Data from conventionally stored (uncovered) poultry/pig manures, excluding cattle FYM.

6 TOTAL NITROGEN

6.1 Total N concentrations and cumulative losses

Total N concentrations in pig FYM leachates generally decreased over both the 6 and 12 month storage periods at ADAS Gleadthorpe (Defra project WA0716; Figure 6). For example, leachate N concentrations from the conventional heap (6 months storage) were initially 1.1 g/l and decreased to 0.3 g/l by the end of storage, and from the conventional heap (12 months storage) decreased initially from 1.5 g/l to 0.5 g/l by the end of storage. Cumulative total N losses from the pig FYM heaps (Figure 7) followed a similar pattern to leachate N concentrations, with greater losses at the start of the experimental period.

(a)



(b)

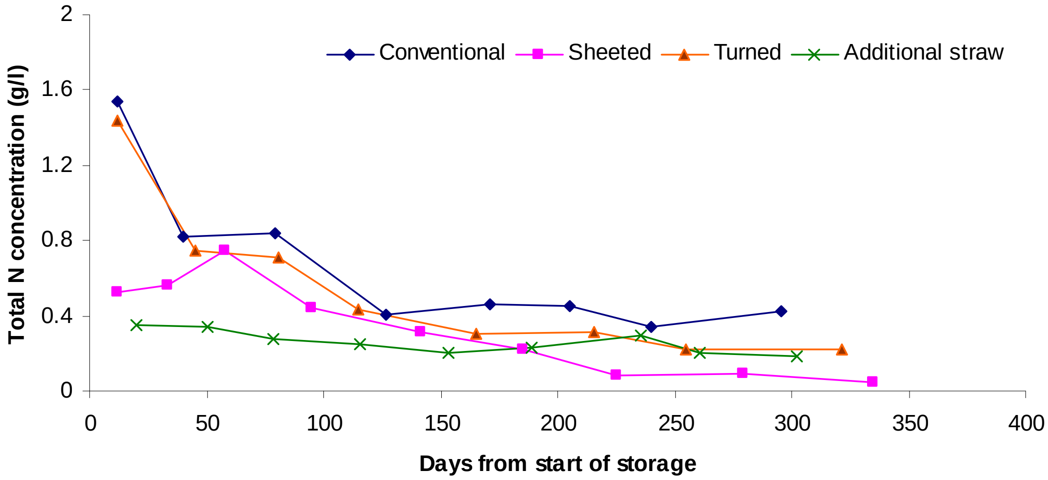


Figure 6: Leachate total N concentrations from pig FYM stored at ADAS Gleadthorpe for (a) 6 and (b) 12 months (Defra project WA0716)

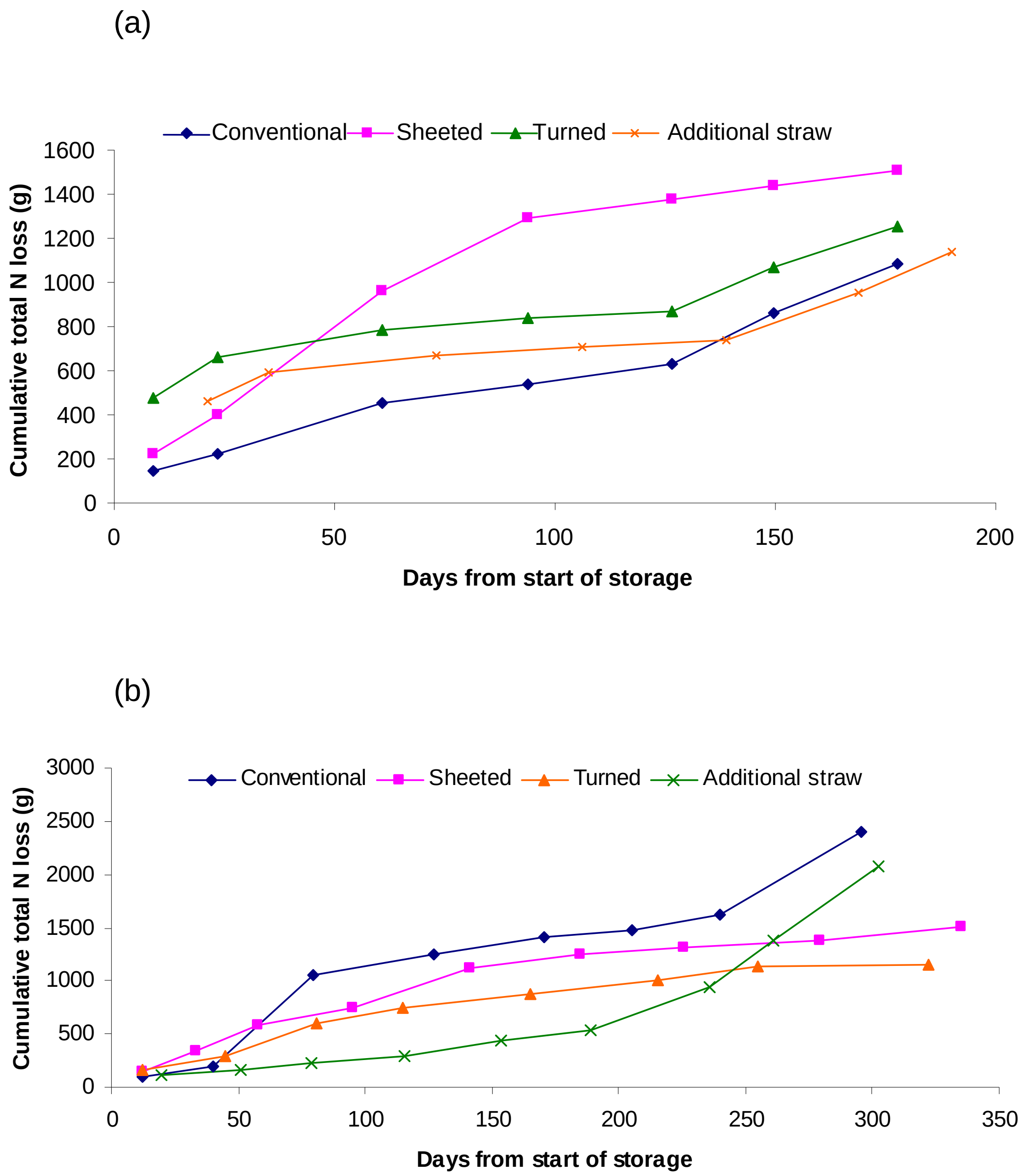


Figure 7: Cumulative total N loss in leachate from pig FYM stored at ADAS Gleadthorpe for (a) 6 and (b) 12 months (Defra project WA0716)

Total N concentrations (and losses) in broiler litter leachates remained relatively stable throughout the storage period (Defra project WA0716; Figures 8 and 9) in the range 1–5 g/litre. In contrast, leachate N concentrations from uncovered layer manure heaps generally decreased throughout the storage period, ranging from 4–8 g/l at the start and 1–6 g/l at the end of storage (Defra project WA0712; Figure 10). Similarly, layer manure leachate total N concentrations (Defra project W0651) tended to decrease throughout the storage period, with concentrations ranging from 6–10 g/l at the start of storage and falling to *c.*2 g/l at the end of storage (Figure 11).

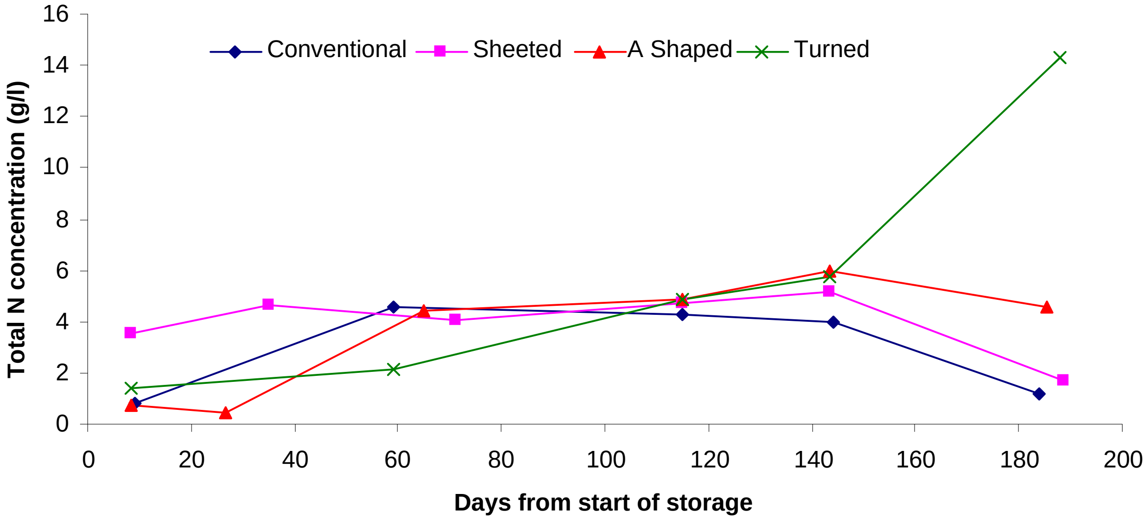


Figure 8: Leachate total N concentrations in broiler litter stored at ADAS Gleadthorpe for 6 months (Defra project WA0716)

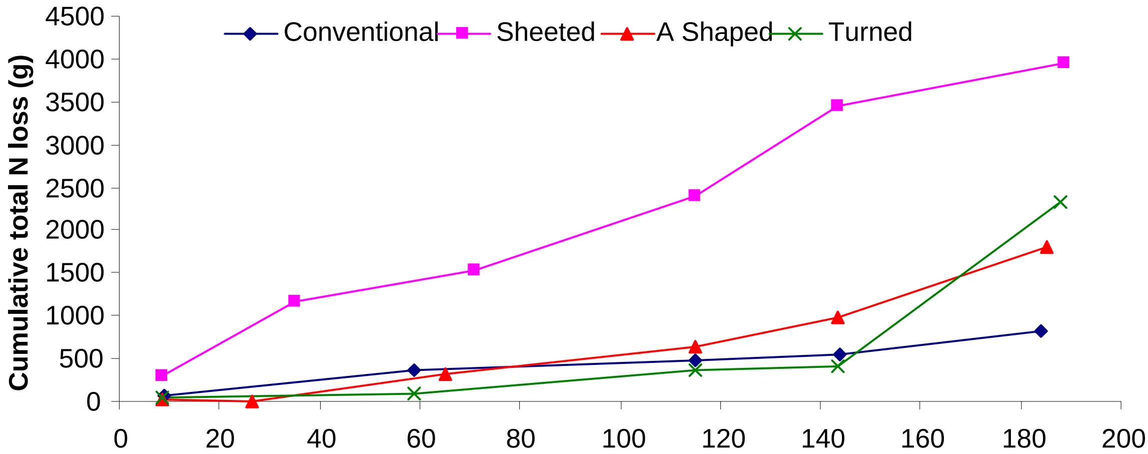


Figure 9: Cumulative total N losses from broiler litter stored at ADAS Gleadthorpe for 6 months (Defra project WA0716)

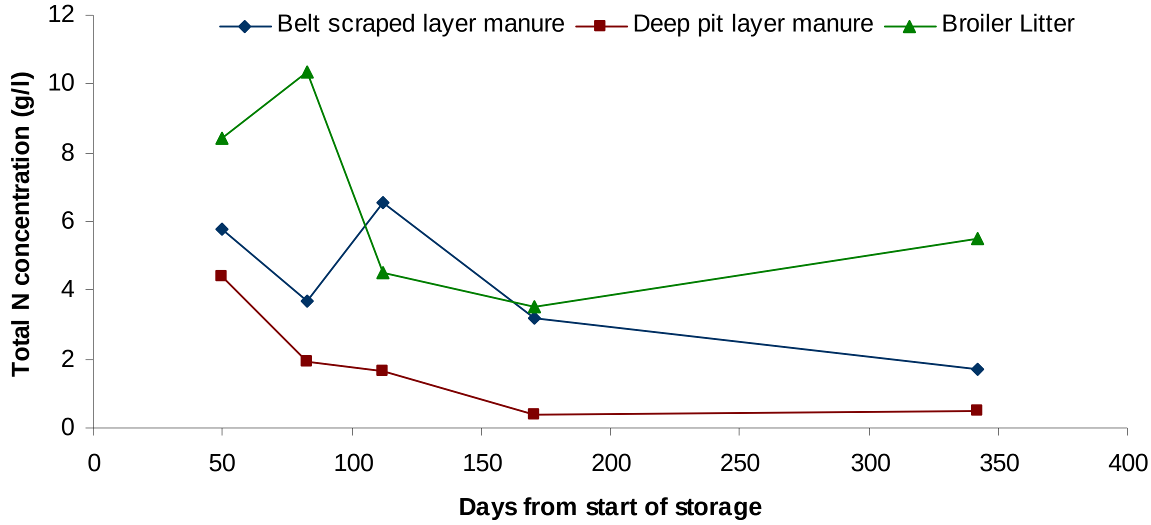


Figure 10: Leachate total N concentrations for uncovered poultry manure heaps at ADAS Gleadthorpe (Defra project WA0712)

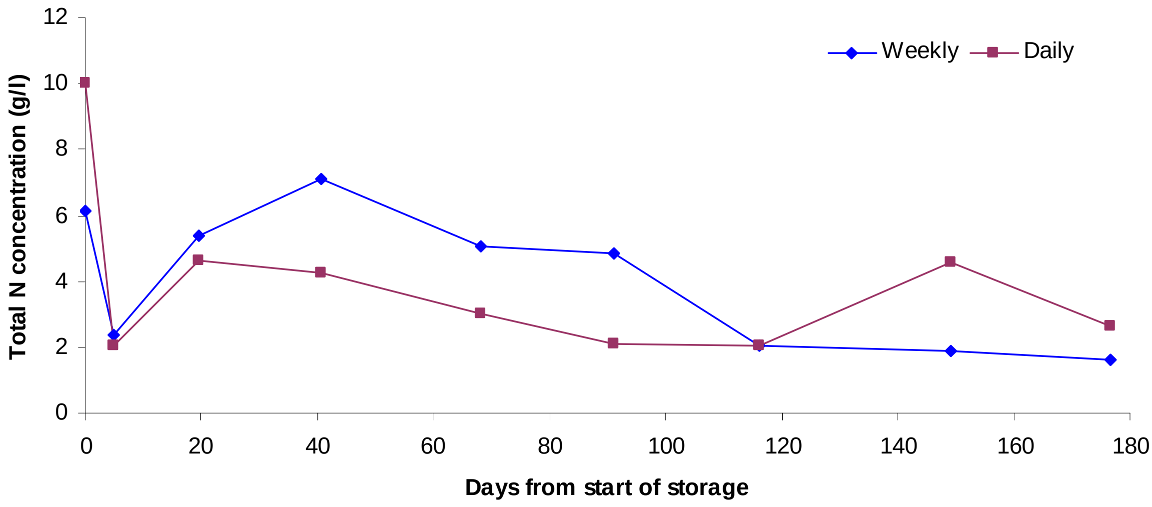


Figure 11: Leachate total N concentrations for layer manure heaps at ADAS Gleadthorpe (Defra project WA0651)

Notably, leachate total N concentrations were generally higher from poultry manure than from pig FYM heaps.

6.2 Total N losses

Cattle FYM studies at North Wyke (Defra project WA0716) measured similar (*P*>0.05) total N leachate losses from all the storage treatments; mean value 2.5% of total N into store (4 months storage) and 1.2% of total N into store (11 months storage). Also, at North Wyke leachate total N losses from cattle FYM stored for *c.*10 months (Defra project WA0632) were 3.7% and 5% of total N inputs into store over the two study periods, respectively (Table 4).

Table 4: Total N losses in cattle FYM leachates. Values in parenthesis are N losses as a % of total N into store.

Defra project	Site	Storage period and treatment	Total N (kg)
WA0716	North Wyke	4 months storage	
		Conventional	0.33 (1.5%)
		50% extra straw	0.40 (1.6%)
		100% extra straw	0.83 (3.8%)
		Sheeted	0.60 (3.1%)
		MEAN	***0.54 (2.5%)***
WA0716	North Wyke	11 months storage	
		Conventional	0.54 (1.5%)
		50% extra straw	0.32 (1.0%)
		100% extra straw	0.27 (0.8%)
		Sheeted	0.50 (1.4%)
		MEAN	***0.41 (1.2%)***
WA0632	North Wyke	10 months storage	
		Jan - Oct 1999	2.6 (3.7%)
		Jan - Oct 2000	5.1 (5.0%)
		MEAN	***3.9 (4.4%)***

At ADAS Gleadthorpe (Defra project WA0716), total N leachate losses measured from pig FYM heaps were similar (*P*>0.05) from all storage treatments; mean value 3.2% of total N into store (6 months storage) and 4.2% of total N into store (12 months storage), Table 5. At ADAS Terrington, total N leachate losses from pig FYM heaps stored for 6–9 months were equivalent to a mean of 1.5% of total N into store (Defra project WA0632, Table 5).

Table 5: Total N, total P and total K losses in pig FYM leachates. Values in parenthesis are nutrient losses as a % of total nutrient into store.

Defra project	Site	Storage period and treatment	Total N (kg)	Total P (g)	Total K (g)
WA0716	ADAS Gleadthorpe	6 months storage			
		Conventional	1.08 (2.8%)	274 (4.1%)	7075 (15.5%)
		Sheeted	1.51 (4.3%)	187 (2.3%)	5796 (15.6%
		Extra straw	0.84 (2.5%)	303 (3.8%)	5759 (16.7%)
		Turned	1.26 (3.2%)	273 (3.0%)	6325 (13.4%)
		MEAN	***1.17 (3.2%)***	***259 (3.4%)***	***6239 (15.3%)***
WA0716	ADAS Gleadthorpe	12 months storage			
		Conventional	1.65 (5.3%)	482 (7.0%)	12129 (37.0%)
		Sheeted	1.39 (4.6%)	326 (5.5%)	7465 (26.4%)
		Extra straw	1.04 (3.0%)	674 (8.2%)	9437 (24.6%)
		Turned	1.15 (4.1%)	672 (12.5%)	8519 (32.5%)
		MEAN	***1.31 (4.2%)***	***539 (8.3%)***	***9388 (30.1%)***
WA0632	ADAS Terrington	6-9 months storage			
		Feb-Oct 1998	0.20 (1.1%)	-	-
		Feb-Sep 1999	0.25 (1.6%)	-	-
		Aug 1998-Feb 1999	0.20 (1.5%)	-	-
		Aug 1999-Jan 2000	0.28 (1.6%)	-	-
		MEAN	***0.23 (1.5%)***		

For broiler litter, mean total N losses were equivalent to 1.5% of total N into store at ADAS Gleadthorpe and 5.9% at North Wyke (Defra project WA0716, Table 6). Also, leachate total N losses were equivalent to *c.*0.5% of total N into store from uncovered poultry manure heaps and <0.1% from covered poultry manure heaps at ADAS Gleadthorpe (Defra project WA0712; Table 6). Similarly, total N losses from daily or weekly belt-scraped layer manure heaps at ADAS Gleadthorpe were equivalent to *c*.1% of total N into store (Defra project WA0651; Table 6).

Table 6: Total N, total P and total K losses in poultry manure leachates. Values in parenthesis are nutrient loss as a % of total nutrient into store.

Defra project	Site (manure type)	Storage period and treatment	Total N (kg)	Total P (g)	Total K (g)
WA0716	ADAS Gleadthorpe. Broiler litter	6 months storage			
		Conventional	1.35 (0.8%)	43.9 (0.03%)	1735 (1.0%)
		A-shaped	1.79 (1.1%)	58.8 (0.04%)	2492 (1.5%)
		Sheeted	4.72 (2.9%)	83.5 (0.05%)	3810 (2.3%)
		Turned	2.33 (1.3%)	49.9 (0.03%)	2499 (1.4%)
		MEAN	***2.55 (1.5%)***	***59.0 (0.04%)***	***2634 (1.6%)***
WA0716	North Wyke. Broiler litter.	6 months storage			
		Conventional	14.6 (8.2%)	-	-
		Sheeted	13.9 (8.0%)	-	-
		Roofed	5.35 (3.1%)	-	-
		Turned	7.78 (4.4%)	-	-
		MEAN	***10.4 (5.9%)***	-	-
WA0712	ADAS Gleadthorpe Broiler litter:	11 months storage			
		Covered	0.38 (0.09%)	40 (0.04%)	670 (0.4%)
		Uncovered	1.91 (0.4%)	390 (0.4%)	5590 (3%)
	Deep pit layer manure:	*Covered*	0.10 (0.03%)	10 (0.02%)	220 (0.1%)
		Uncovered	1.24 (0.4%)	220 (0.2%)	4970 (3%)
	Belt-scraped layer manure	*Covered*	0.35 (0.09%)	30 (0.04%)	480 (0.4%)
		Uncovered	2.67 (0.7%)	130 (0.2%)	2700 (2%)
		MEAN	***1.11 (0.3%)***	***137 (0.2%)***	***2438 (1.5%)***
WA0651	ADAS Gleadthorpe Layer manure	*c*.12 months storage			
		Daily belt scraped	1.0 (0.9%)	-	-
		Weekly belt scraped	1.0 (1.0%)	-	-
		MEAN	***1.0 (1.0%)***	-	-

6.3 Summary

In the majority of experiments, the highest total N concentrations were measured at the beginning (i.e. in the first month) of leachate generation, with concentrations up to *c.*2 g/l from pig FYM heaps and *c.*10 g/l from poultry manure heaps. Thereafter, concentrations declined from the pig FYM heaps to <0.5 g/l, but remained relatively stable from the poultry manure heaps. Similarly, total leachate N losses from the pig FYM heaps were greater at the start of storage and declined thereafter. Sommer (2001) also showed that total N concentrations and losses decreased throughout the period of FYM storage.

Total leachate N losses over the storage period were generally low ranging from 0.8–5.3% of total N into store from uncovered cattle/pig FYM heaps, and 0.4–8.2% of total N into store from uncovered poultry manure heaps (Figure 12). There loss values were in good agreement with the range of N losses from cattle FYM (0.4–3.4%) reported in the published literature (Chadwick, 2005; Sommer and Dahl, 1999; Sommer, 2001).

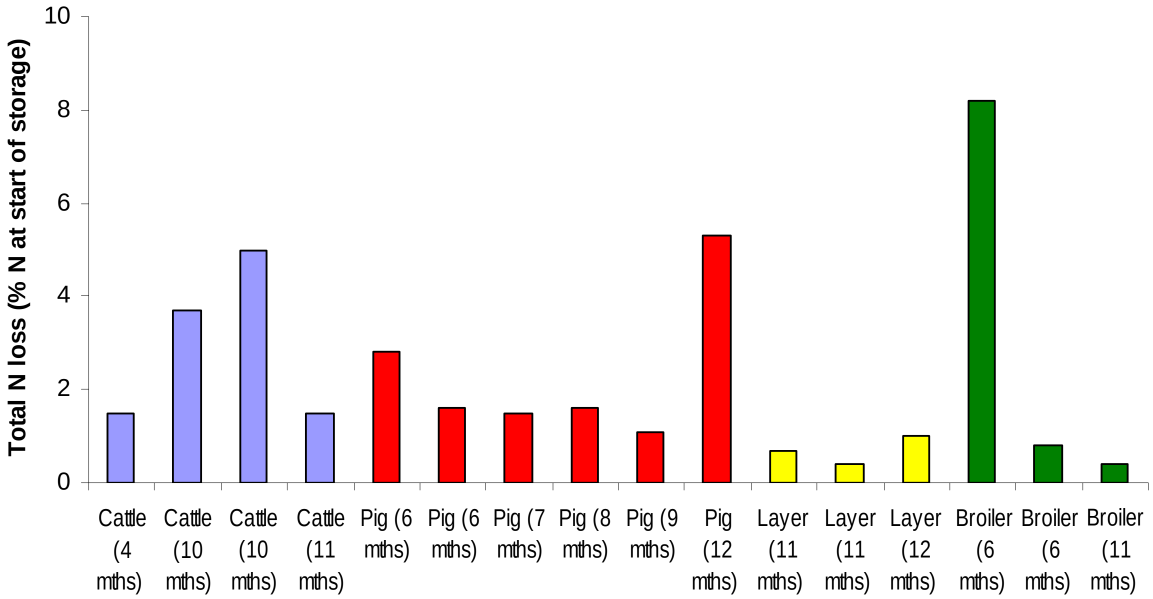


Figure 12: Leachate total N losses from conventional solid manure heaps (Defra projects WA0651, WA0632, WA0712 and WA0716)

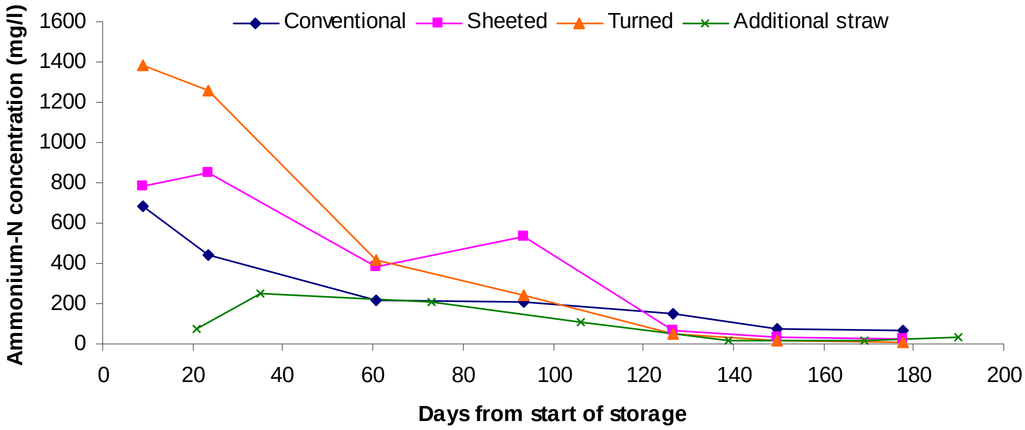
Greater leachate total N losses were measured from uncovered (0.5% of total N into store) than covered (<0.1% of total N into store) poultry manure heaps (Defra project WA0712), demonstrating that covering poultry manure field heaps was an effective method of reducing leachate nitrogen losses.

7 AMMONIUM-N AND NITRATE-N

7.1 Ammonium-N concentrations and cumulative losses

Ammonium-N concentrations in pig FYM heap leachates decreased over the 6 and 12-month storage periods on all treatments (Defra project WA0716; Figure 13). At the start of storage, ammonium-N concentrations from the conventional heap treatments were *c.*700 mg/l (6-month storage) and *c.*1100 mg/l (12 month storage). At the end of the storage period, concentrations had fallen to <100 mg/l. Notably, leachate concentrations were always above the limit value of 0.78 mg/l ammonium-N specified in the Freshwater Fish Directive (EU, 2006a). Similarly, leachate ammonium-N losses were generally greatest at the start of storage and decreased over the storage period (Figure 14).

(a)



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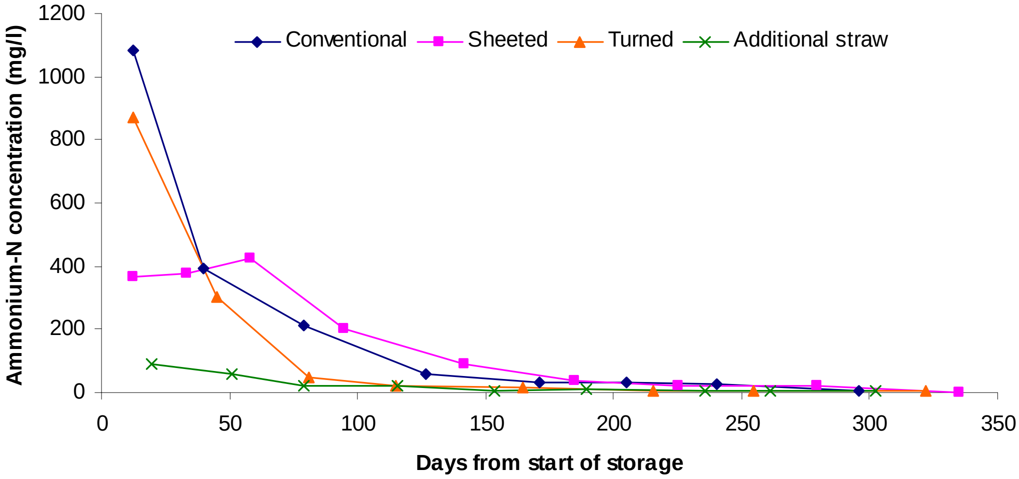
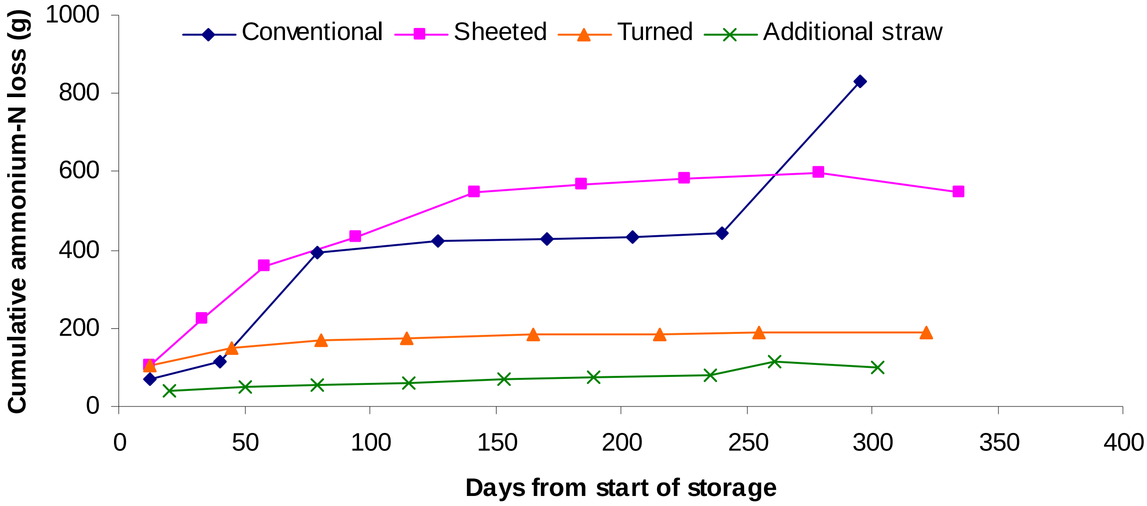


Figure 13: Leachate ammonium-N concentrations from pig FYM stored at ADAS Gleadthorpe for (a) 6 and (b) 12-months (Defra project WA0716)

(a)



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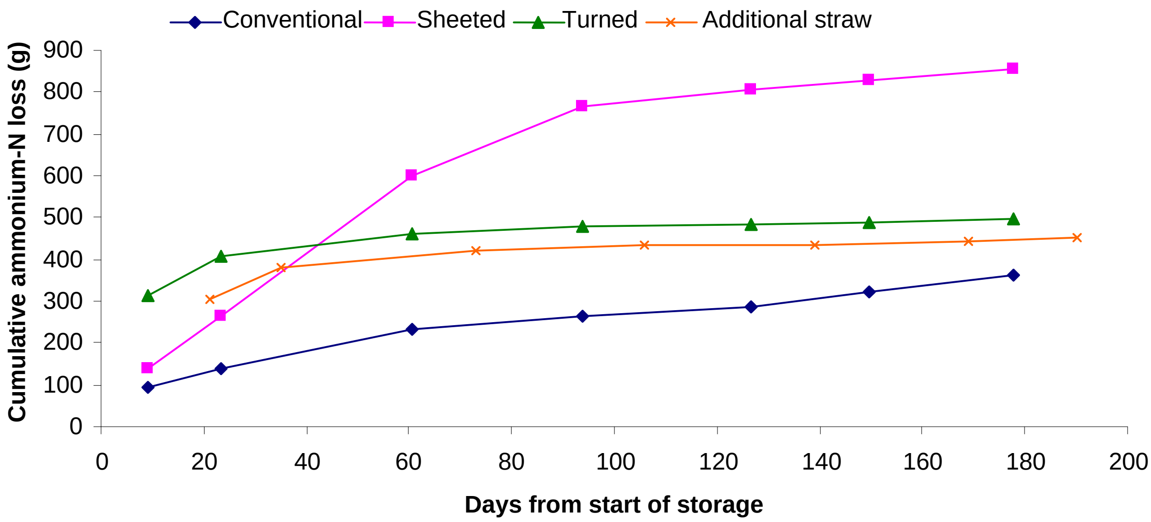


Figure 14: Cumulative leachate ammonium N losses from pig FYM stored at ADAS Gleadthorpe for (a) 6 and (b) 12-months (Defra project WA0716)

Ammonium-N concentrations in broiler litter heap leachates (mean concentration *c.*3000 mg/l) were higher than in pig FYM leachates (maximum value 1400 mg/l). In contrast to the pig FYM leachates, ammonium-N concentrations and losses remained relatively stable over the storage period (Figures 15 and 16). Cumulative ammonium-N losses were greater from the sheeted treatments due to the collection of additional runoff volumes compared with the conventional and A-shaped heaps (Figure 16).

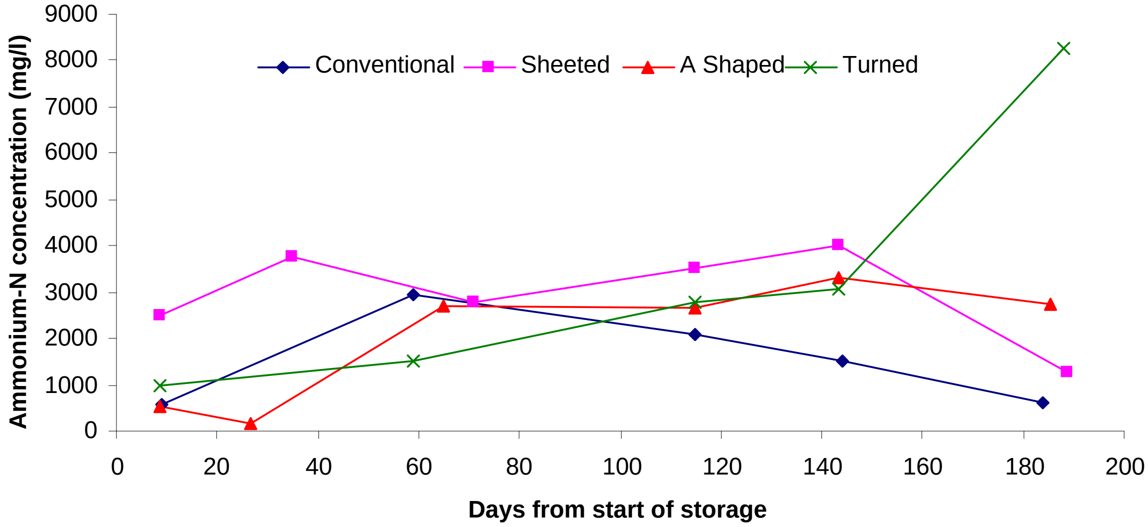


Figure 15: Leachate ammonium-N concentrations from broiler litter stored at ADAS Gleadthorpe for 6 months (Defra project WA0716)

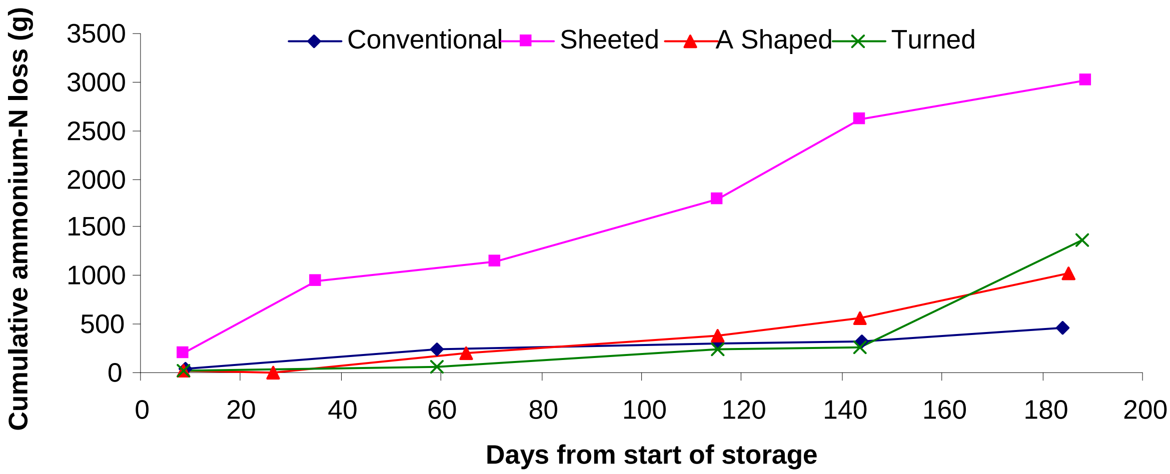


Figure 16: Cumulative leachate ammonium N losses from broiler litter stored for 6-months (Defra project WA0716)

Broiler litter heap leachates (Defra project WA0712) had a mean ammonium-N concentration of *c.*4000 mg/l, belt-scraped layer manure leachates *c.*1500 mg/l and deep pit layer manure leachates *c.*650 mg/l (Figure 17). Leachate ammonium-N concentrations generally decreased as the experimental period progressed and by the end of storage ammonium-N concentrations ranged from *c.*1000 mg/l (layer manures) to *c.*3000 mg/l (broiler litter), compared with <100 mg/l from pig FYM heaps at the end of storage.

Mean leachate ammonium-N concentrations were *c.*3000 mg/l from weekly belt-scraped and daily belt-scraped layer manures (Defra project WA0651). In general, ammonium N concentrations decreased to a small extent over the storage period (Figure 18).

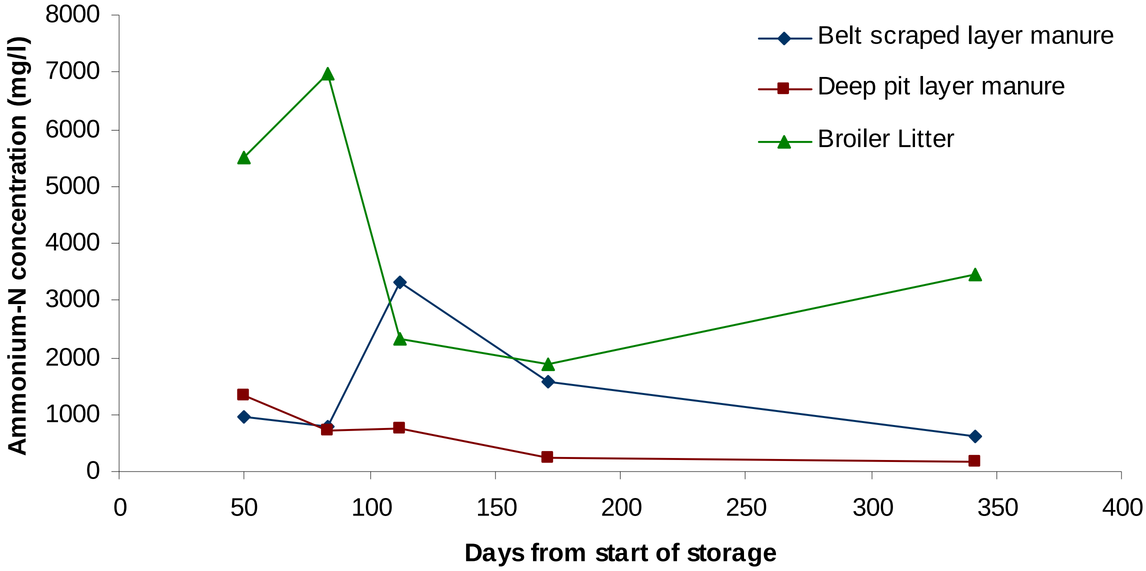


Figure 17: Leachate ammonium-N concentrations from uncovered poultry manures stored at ADAS Gleadthorpe for 12-months (Defra project WA0712)

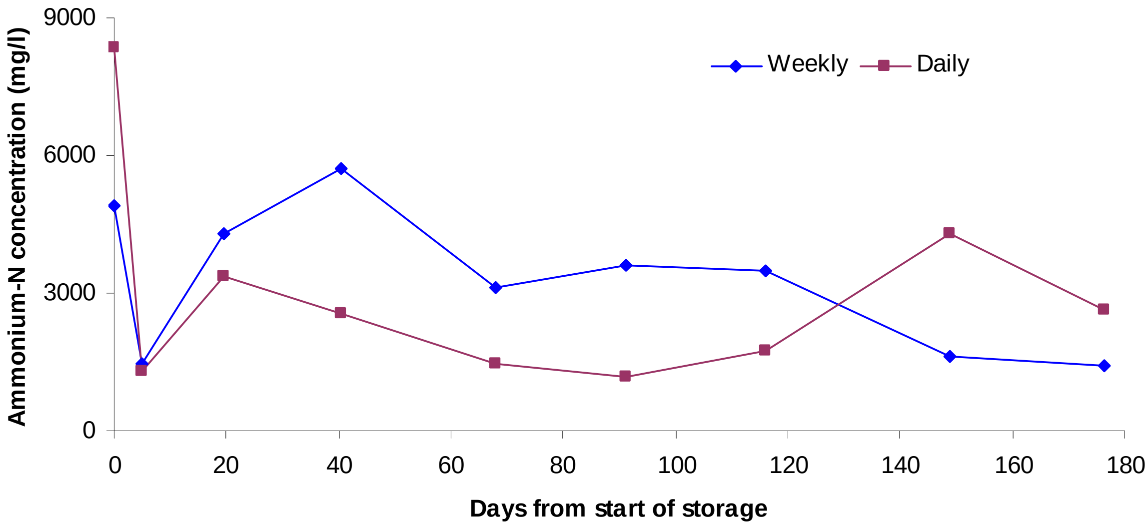
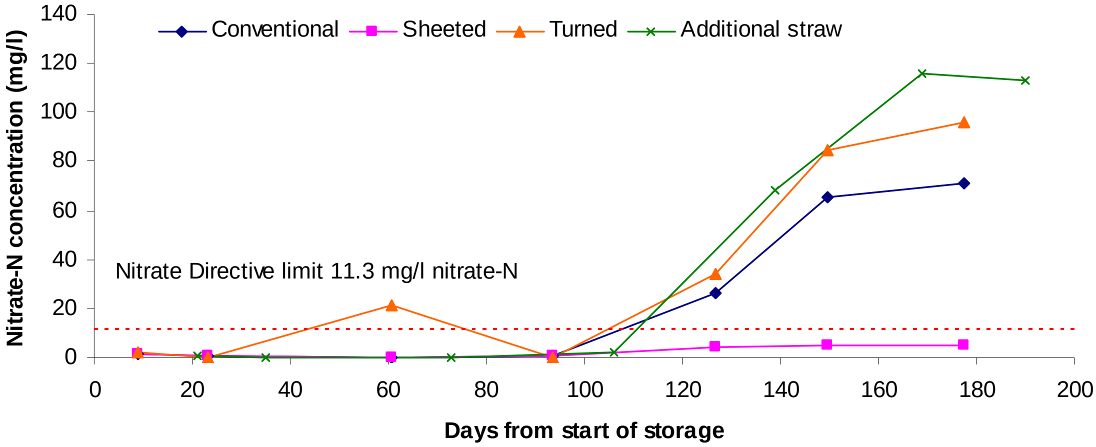


Figure 18: Leachate ammonium-N concentrations from belt-scraped layer manures (removed daily or weekly) stored at ADAS Gleadthorpe for 6-months (Defra project WA0651)

7.2 Nitrate-N concentrations and loss patterns

Nitrate-N concentrations in pig FYM heap leachates (Defra project WA0716) tended to increase throughout the storage period (Figure 19). For example, leachate nitrate-N concentrations (6 months conventional heap storage) were initially *c.*2 mg/l and increased to *c.*70 mg/l by the end of storage. In contrast, nitrate-N concentrations in leachates from sheeted pig FYM heaps remained fairly constant throughout both the 6 and 12-month storage periods at means of *c.*2 and *c.*8 mg/l, respectively. Cumulative nitrate-N losses from uncovered pig FYM heaps stored for 6 and 12-months increased over the storage period, with losses from the 12-months storage period higher than from the 6-months storage period (Figure 20).

(a)



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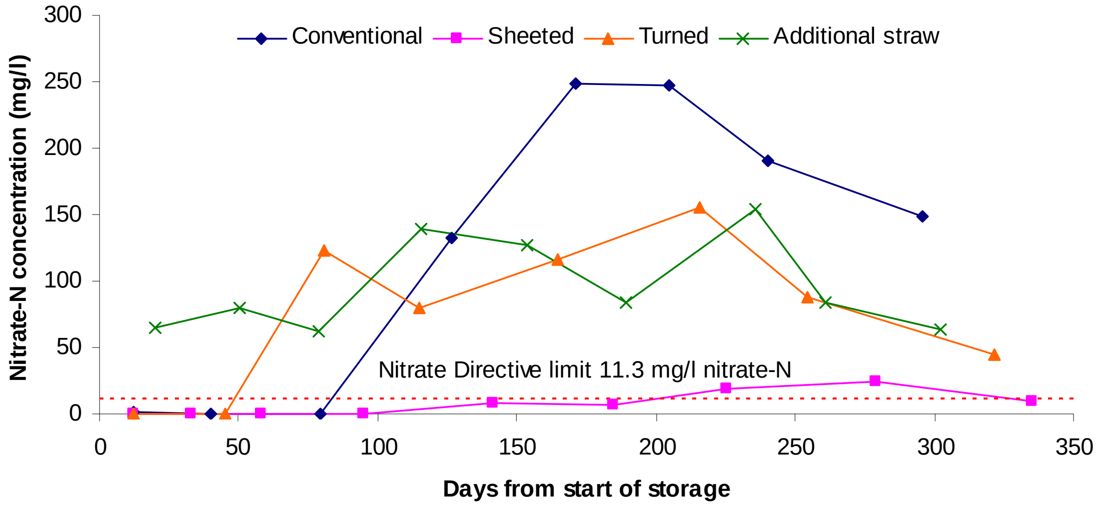
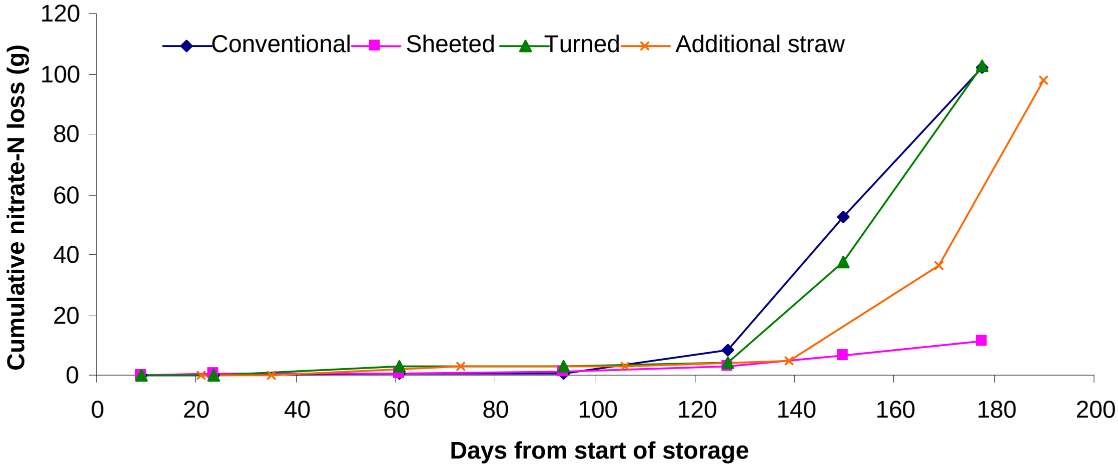


Figure 19: Leachate nitrate N concentrations from pig FYM stored at ADAS Gleadthorpe for (a) 6 and (b) 12-months (Defra project WA0716)

(a)



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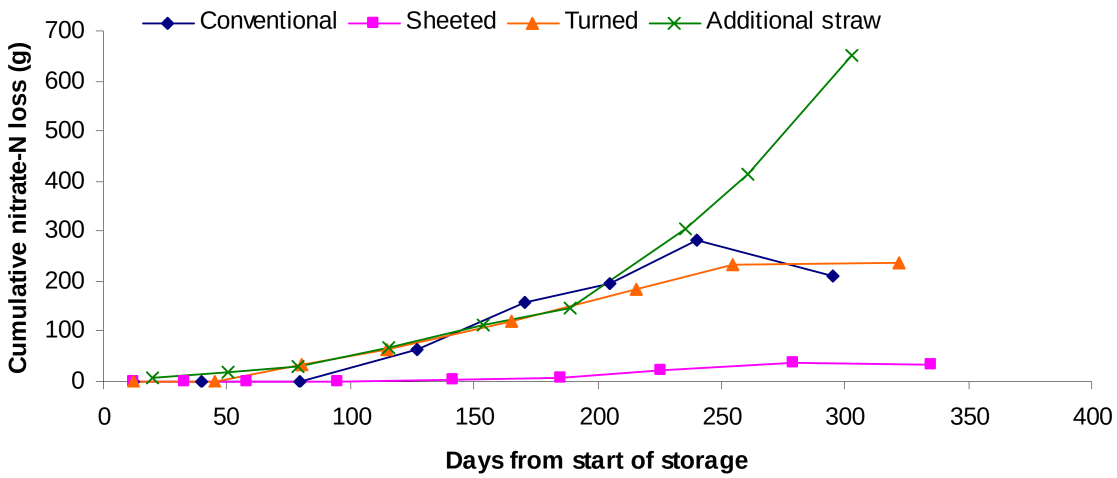


Figure 20: Cumulative leachate nitrate-N losses from pig FYM stored at ADAS Gleadthorpe for (a) 6 and (b) 12-months (Defra project WA0716)

Nitrate-N concentrations in broiler litter heap leachates (Defra project WA0716) were consistently low throughout the storage period (*c.*0.05 mg/l, data not shown). In contrast, nitrate-N concentrations in poultry manure heap leachates (Defra project WA0712) decreased over the 12-months storage period and for all poultry manure types had fallen to <10 mg/l after *c.*6 months storage (Figure 21). Similarly, leachate nitrate-N concentrations from daily/weekly belt-scraped layer manure heaps (Defra project WA0651) were initially *c.*300 mg/l and decreased to <10 mg/l after *c.*150 days of storage (Figure 22).

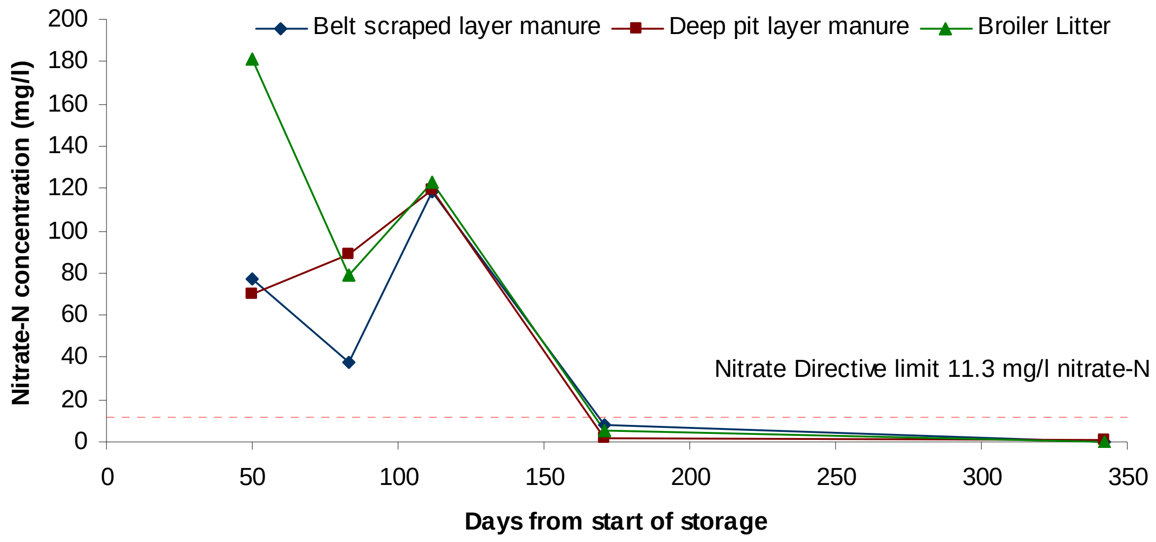


Figure 21: Leachate nitrate-N concentrations from poultry manures stored at ADAS Gleadthorpe for 12-months (Defra project WA0712)

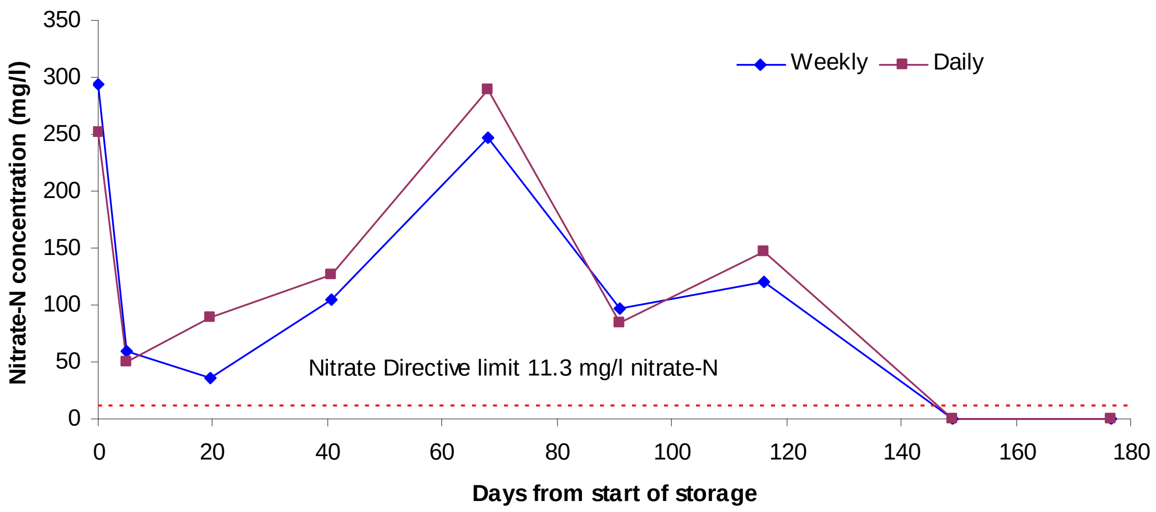


Figure 22: Leachate nitrate-N concentrations from belt-scraped layer manures stored at ADAS Gleadthorpe for 6-months (Defra project WA0651)

7.3 Summary

In general, leachate ammonium-N concentrations (and losses) from both pig FYM and poultry manure heaps were highest at the start of storage (i.e. in the first month of leachate generation) and decreased over time. These findings agree with the work of Parkinson *et al*. (2004) and Sommer (2001) who reported that leachate ammonium-N concentrations from cattle FYM heaps fell progressively over the storage period. Leachate ammonium-N concentrations were consistently higher than the limit value of 0.78 mg/l ammonium-N set in the Freshwater Fish Directive (EU, 2006a), with initial concentrations from poultry manure heaps of over 5000 mg/l and from pig FYM heaps over 1000 mg/l.

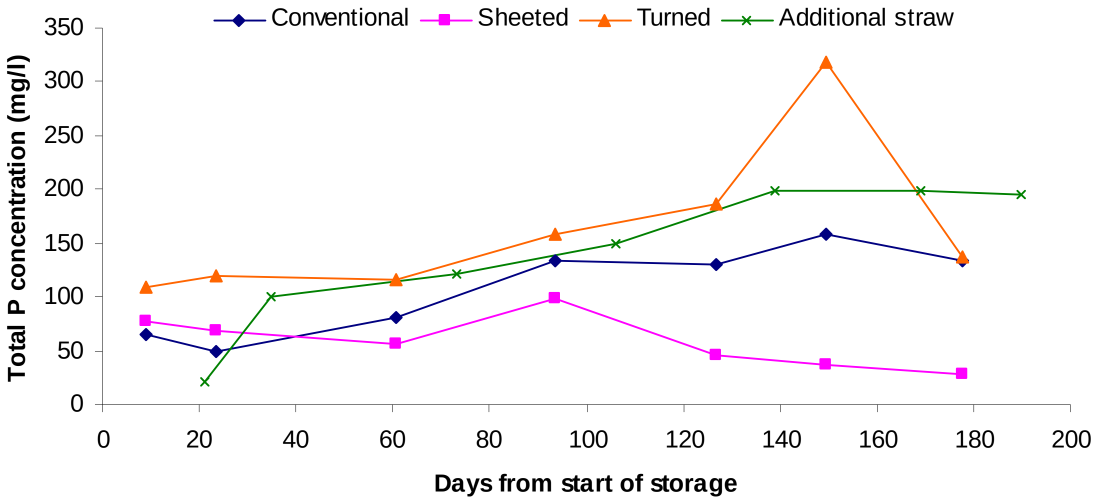
Leachate nitrate-N concentrations (and losses) from poultry manures heaps generally decreased over the storage period, whilst in contrast concentrations (and losses) from pig FYM heaps increased over the storage period. Parkinson *et al*. (2004) also reported that leachate nitrate-N concentrations from cattle FYM heaps increased over time, although in contrast Sommer (2001) reported the highest nitrate-N concentrations at the start of storage. Leachate nitrate-N concentrations often exceeded the Nitrate Directive limit (11.3 mg/l nitrate-N), with concentrations in excess of 100 mg/l commonly measured, particularly during the latter stages of pig FYM storage and from poultry manure heaps.

8 TOTAL PHOSPHORUS

8.1 Total phosphorus concentrations and cumulative losses

Total P concentrations (and losses) in leachates from uncovered pig FYM and poultry manure heaps generally increased to a small extent over the storage period, although concentrations (and losses) decreased over time from the sheeted heaps (Defra project WA0716; Figures 23–26). Mean leachate total P concentrations from the conventional pig FYM heaps were *c.*100 mg/l (6 months storage) and 200 mg/l (12 months storage), and from broiler litter heaps *c.*200 mg/l (Figures 23 and 25).

(a)



(b)

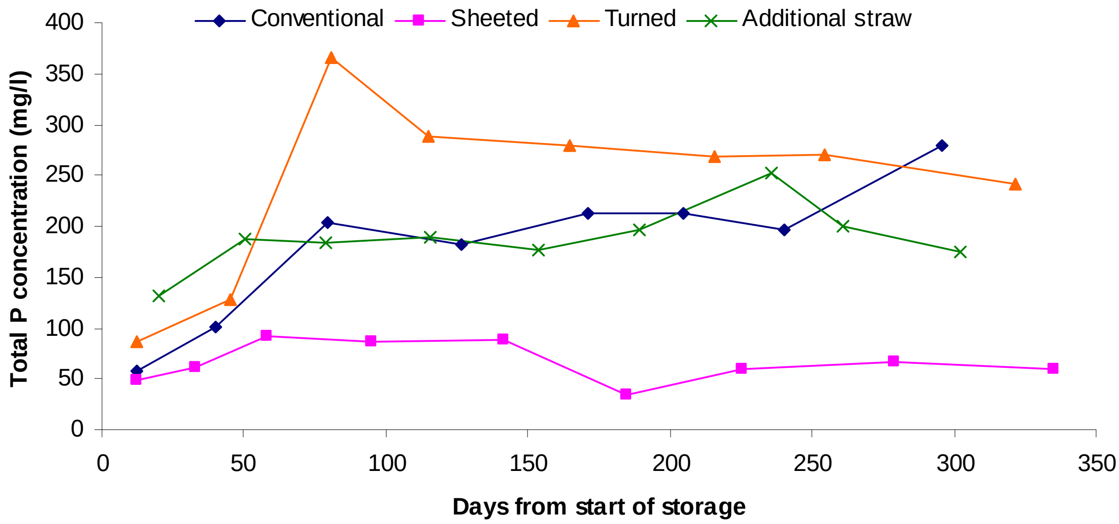
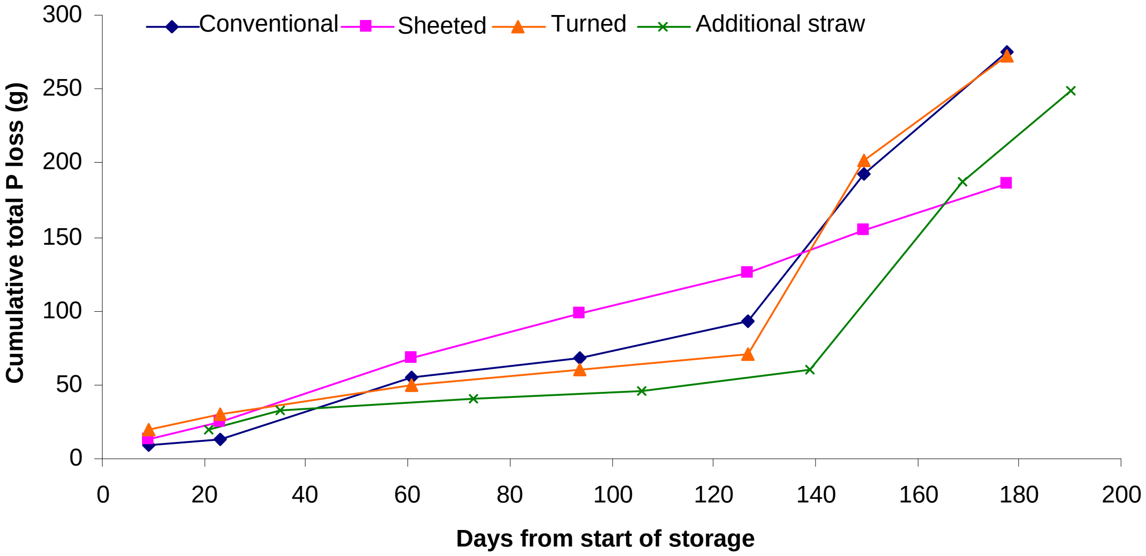


Figure 23: Leachate total P concentrations from pig FYM stored at ADAS Gleadthorpe for (a) 6 and (b) 12-months (Defra project WA0716)

(a)



(b)

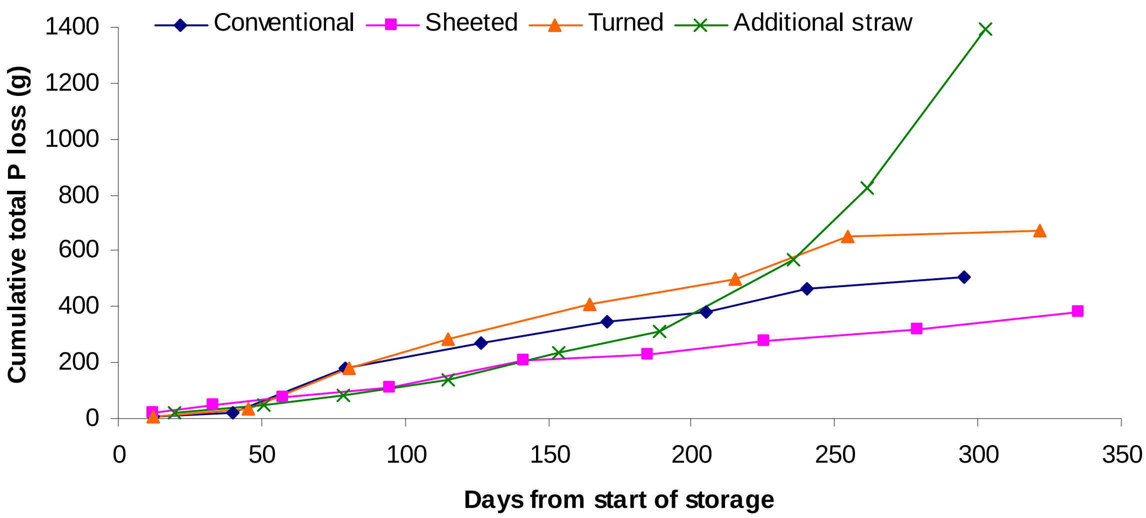


Figure 24: Cumulative leachate total P losses from pig FYM stored at ADAS Gleadthorpe for (a) 6 and (b) 12-months (Defra project WA0716)

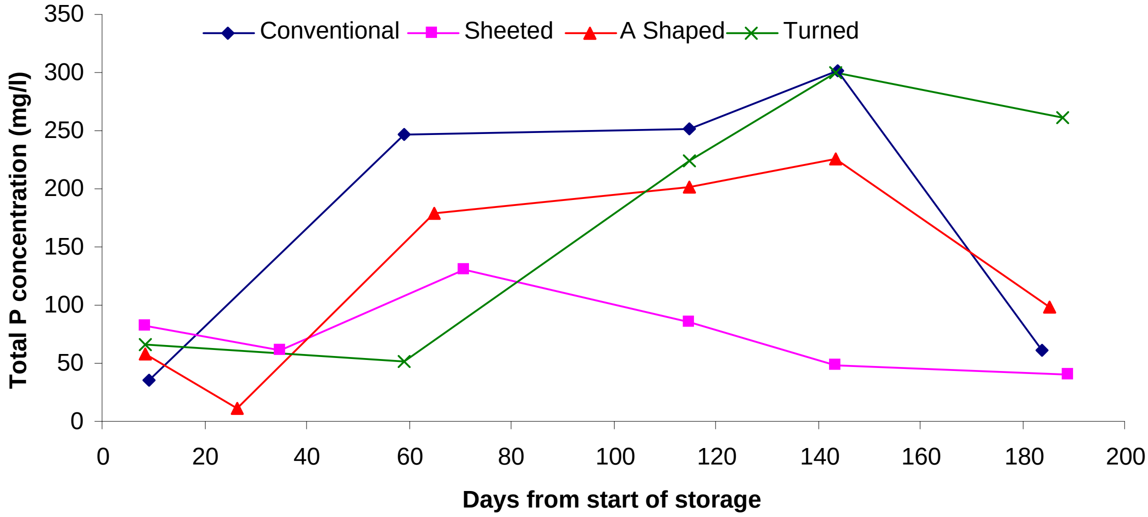


Figure 25: Leachate total P concentrations from broiler litter stored at ADAS Gleadthorpe for 6 months (Defra project WA0716)

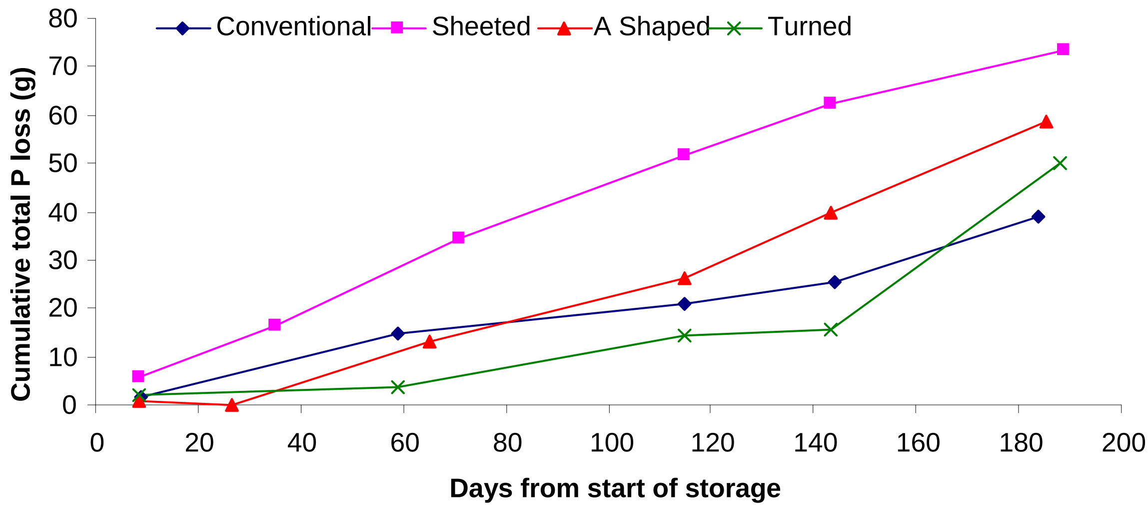


Figure 26: Cumulative leachate total P losses from broiler litter stored at ADAS Gleadthorpe for 6 months (Defra project WA0716)

Total P concentrations in leachates from poultry manure heaps (stored for 12 months; Defra project WA0712) ranged from *c.*1200 mg/l (broiler litter) to *c.*300 mg/l (deep pit and belt-scraped layer manures), with total P concentrations generally decreasing to a small extent over the storage period (Figure 27).

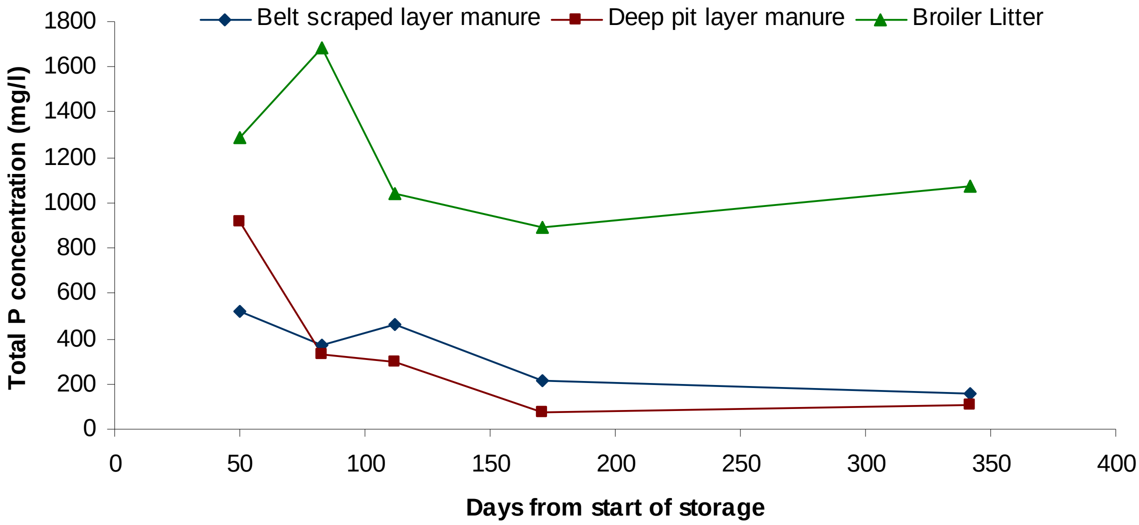


Figure 27: Leachate total P concentrations from poultry manure stored at ADAS Gleadthorpe for 12 months (Defra project WA0712)

8.2 Total phosphorus losses

Leachate total P losses from uncovered pig FYM heaps ranged from 3.0–12.5% of total P into store, with lower losses (range 2.3–5.5%) measured from the sheeted treatments (Table 5). For uncovered poultry manure heaps, leachate total P losses ranged from 0.03–0.4% of total P into store, with lower losses (0.02–0.04%) measured from covered poultry manure heaps (Table 6).

8.3 Summary

There were no strong or consistent patterns in leachate P concentrations or losses from the uncovered pig FYM and poultry manure heaps. Leachate total P losses from uncovered pig FYM heaps were in the range 3.0–12.5% of total P into store, and from uncovered poultry manure heaps in the range 0.03–0.4% of total P into store (Figure 28); in good agreement with the range of P losses from cattle FYM (0.8 to 2.4%) reported in the published literature (Sommer and Dahl, 1999; Sommer, 2001). Notably, covering poultry manure heaps reduced leachate P losses *c*. 8-fold.

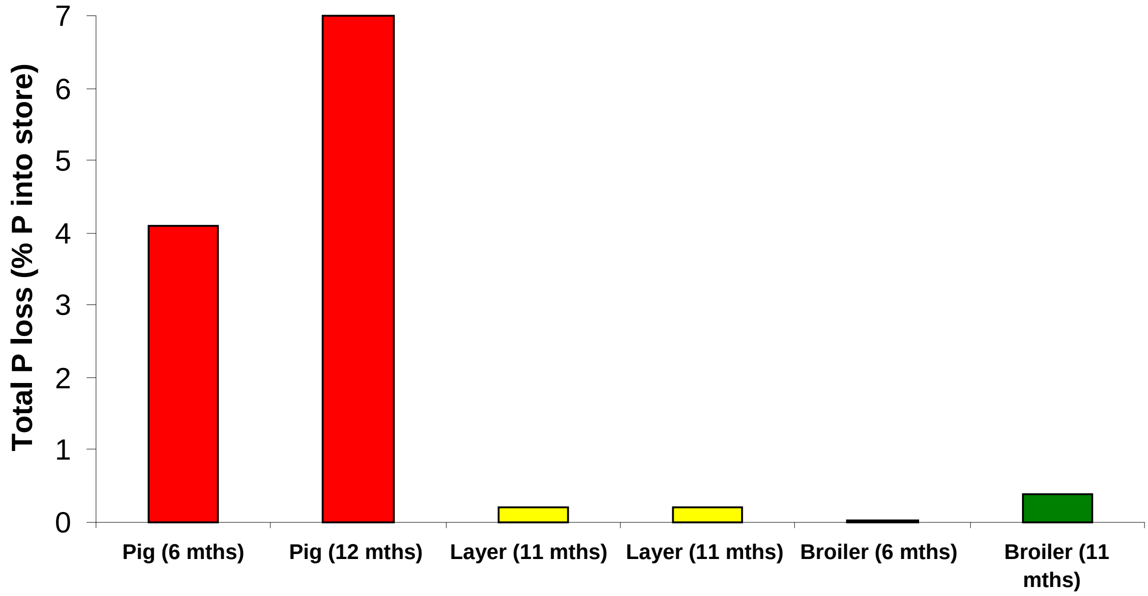


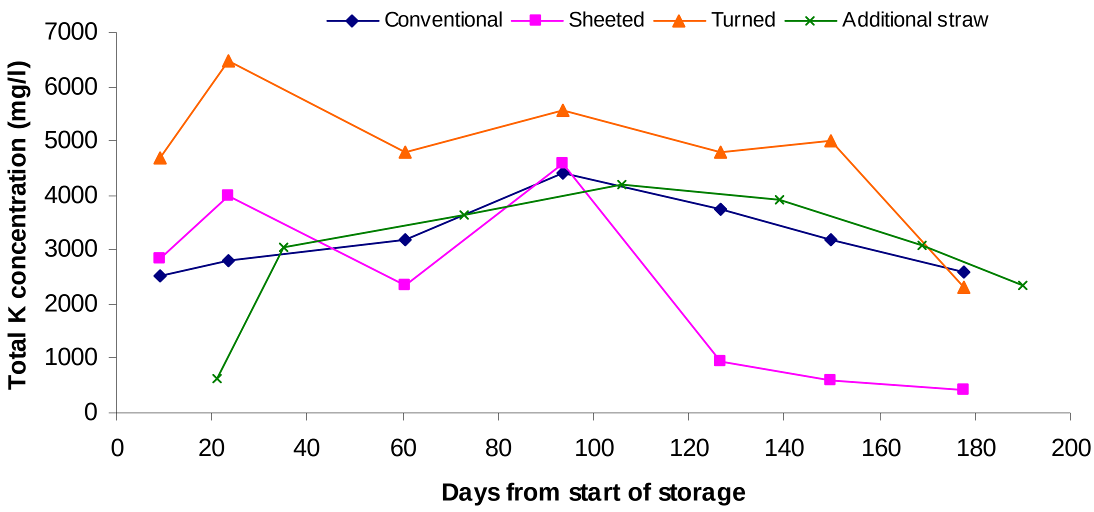
Figure 28: Leachate total P losses from conventional (uncovered) solid manure heaps (Defra projects WA0712 and WA0716)

9 TOTAL POTASSIUM

9.1 Total potassium concentrations and cumulative losses

Total K concentrations in leachates from pig FYM heaps generally decreased to a small extent over both the 6 and 12-months storage periods (Defra project WA0716; Figure 29), with cumulative K losses increasing over the storage period (Figure 30). In contrast, total K concentrations (and losses) in broiler litter heap leachates generally increased over the storage period (Figures 31 and 32), whereas leachate total K concentrations from poultry manure heaps stored for *c.*12 months generally decreased over the storage period (Defra project WA0712; Figure 33).

(a)



(b)

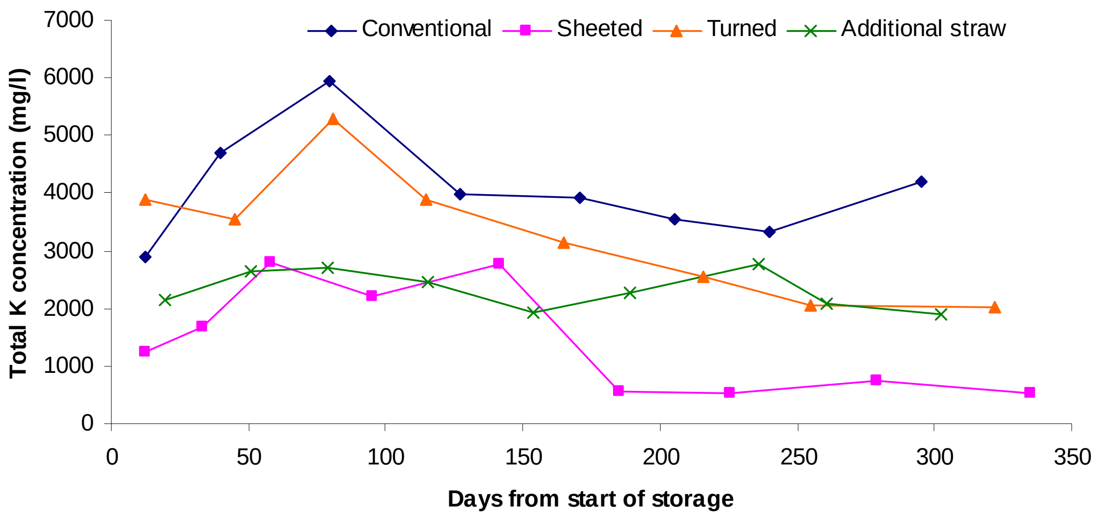
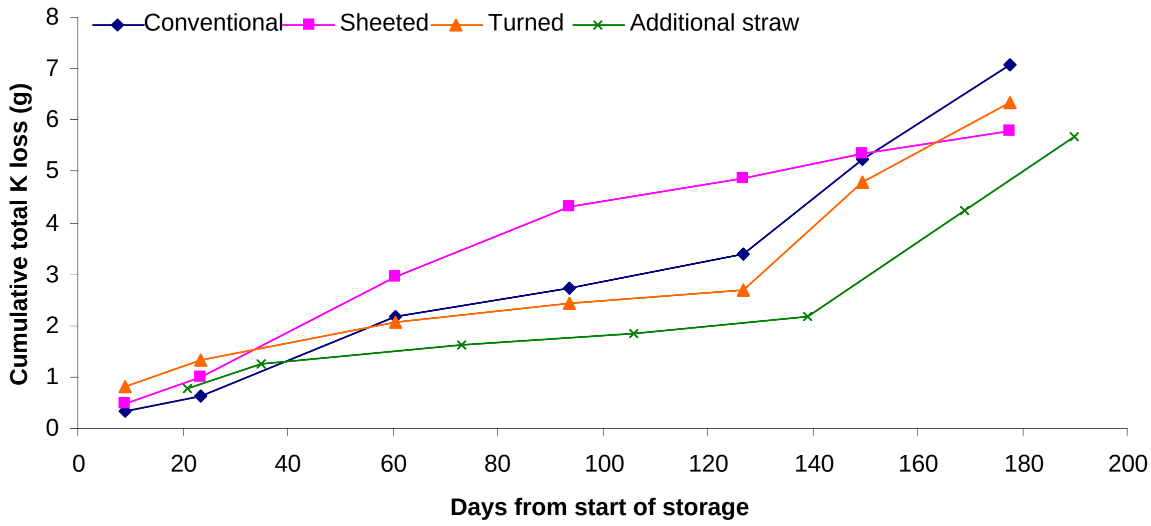


Figure 29: Leachate total K concentrations from pig FYM stored at ADAS Gleadthorpe for (a) 6 and (b) 12-months (Defra project WA0716)

(a)



(b)

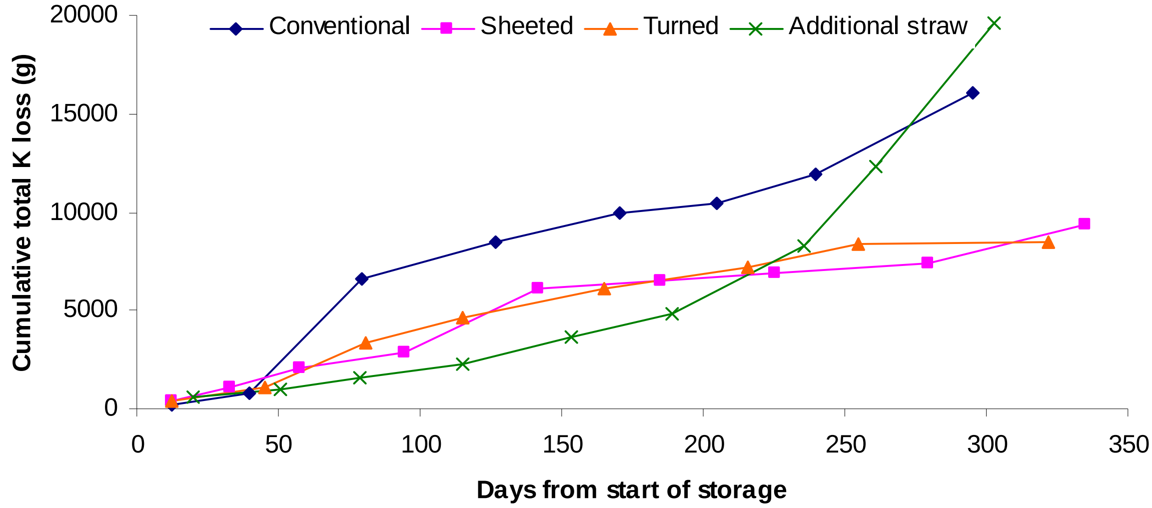


Figure 30: Cumulative leachate total K losses from pig FYM stored at ADAS Gleadthorpe for (a) 6 and (b) 12-months (Defra project WA0716)

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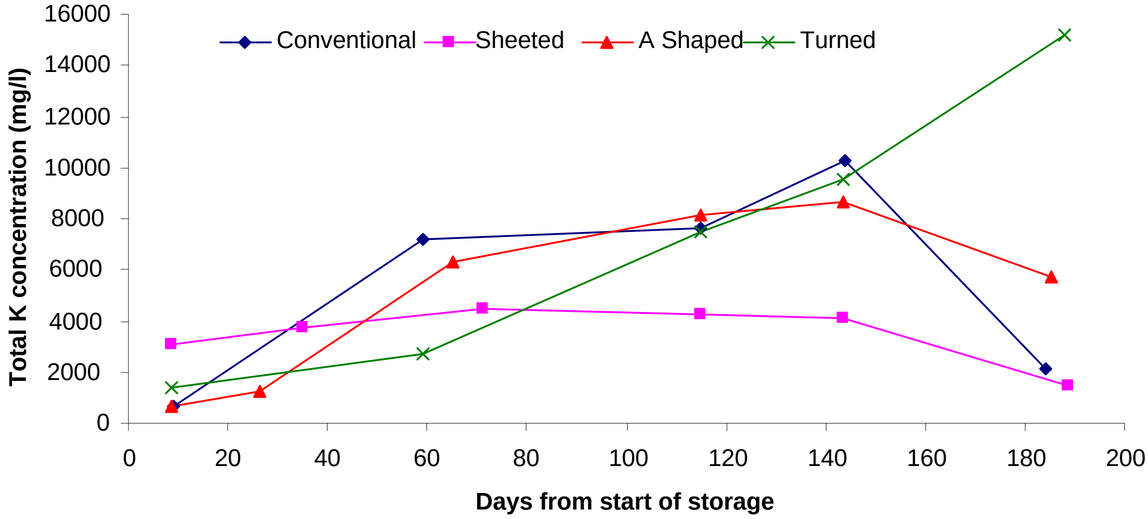


Figure 31: Leachate total K concentrations from broiler litter stored at ADAS Gleadthorpe for 6 months (Defra project WA0716)

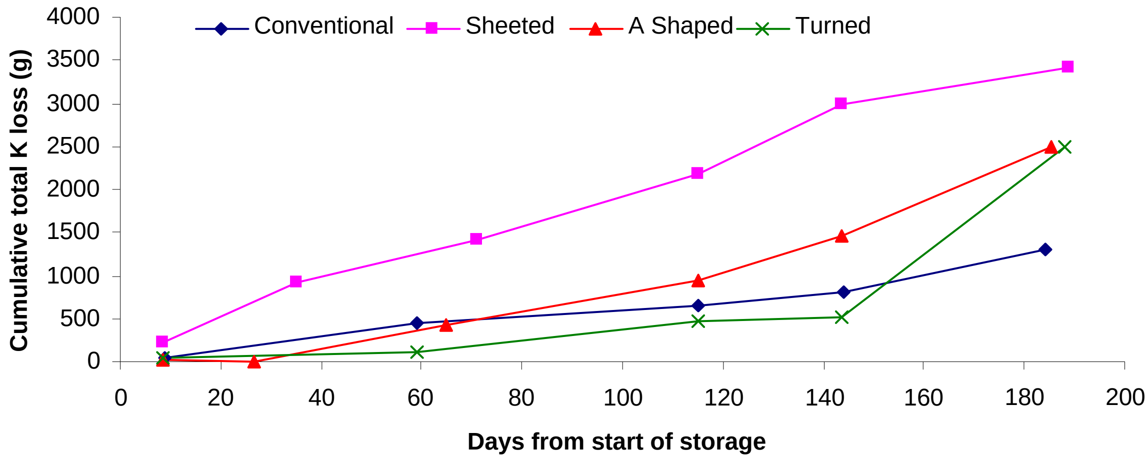


Figure 32: Cumulative leachate total K losses from broiler litter stored at ADAS Gleadthorpe for 6 months (Defra project WA0716)

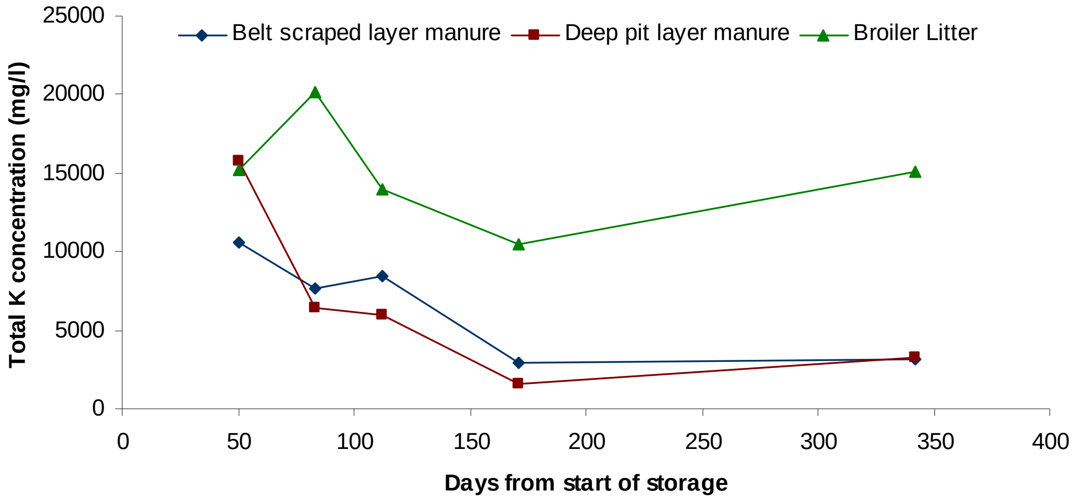


Figure 33: Total K concentrations from poultry manure stored at ADAS Gleadthorpe for 12 months (Defra project WA0712)

9.2 Total potassium losses

Leachate K losses were higher than N or P losses, confirming the greater mobility of K ions. For pig FYM, leachate K losses from the 6 and 12-months uncovered heap treatments were in the range 13.4–37.0% of total K inputs into store (Table 5 and Figure 34). In contrast, uncovered broiler litter leachate losses were in the range 1.0–3.0% (mean=1.7%) of total K inputs into store (Table 6 and Figure 34). Similarly, leachate total K losses (Defra project WA0712) for uncovered layer manure heaps were equivalent to 3% and 2% of total K inputs into the deep pit and belt-scraped layer manure heaps, respectively (Table 6 and Figure 34).

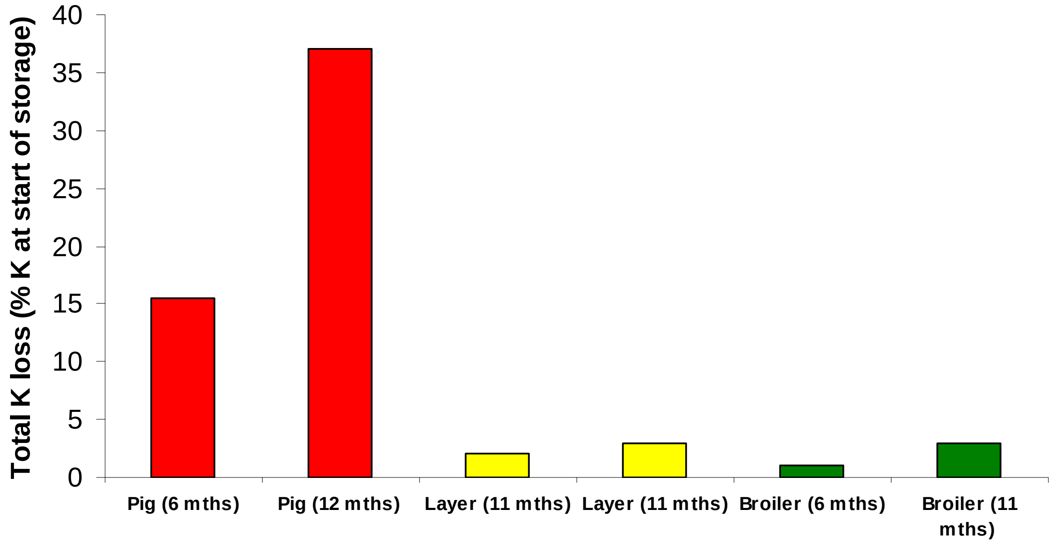


Figure 34. Leachate total K losses from conventional solid manure heaps (Defra projects WA0712 and WA0716)

9.3 Summary

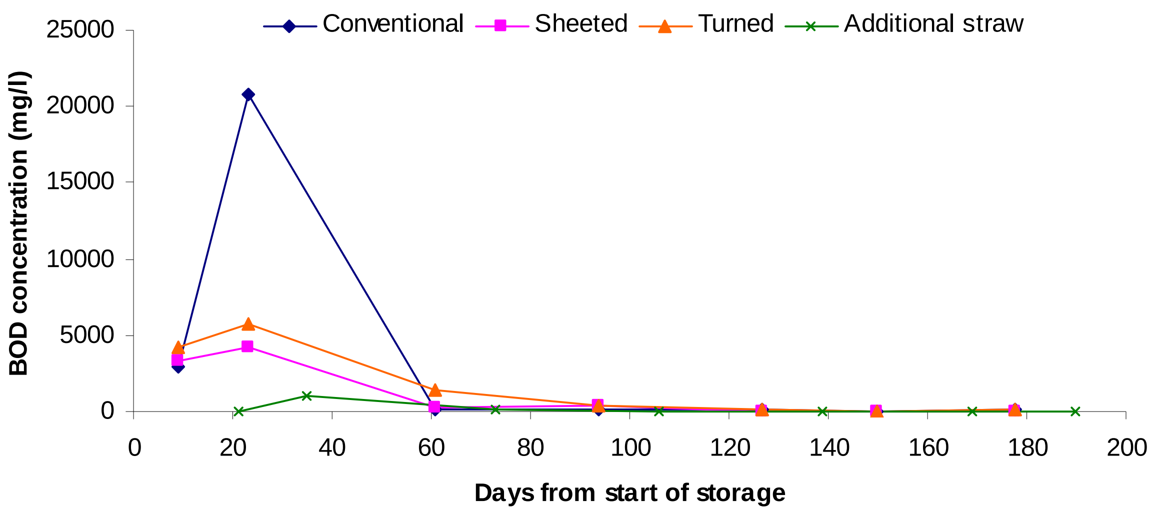
There were no clear patterns in leachate total K concentrations (and losses) during pig FYM and poultry manure storage. However, total K losses from the uncovered pig FYM heaps (range 13.4–37.0%) were substantially greater than those from the uncovered poultry manure heaps (range 1.0–3.0%). Covering poultry manure heaps decreased leachate K losses *c*.9-fold.

10 BIOCHEMICAL OXYGEN DEMAND (BOD)

10.1 BOD concentrations

Leachate BOD concentrations from pig FYM heaps stored for either 6 or 12-months were initially in the range 1,000-20,000 mg/l during the first month of leachate generation, with concentrations falling after around 2 months to <500 mg/l (Defra project WA0716; Figure 35). Notably, leachate BOD concentrations from the additional straw treatment were much lower than the other treatments.

(a)



(b)

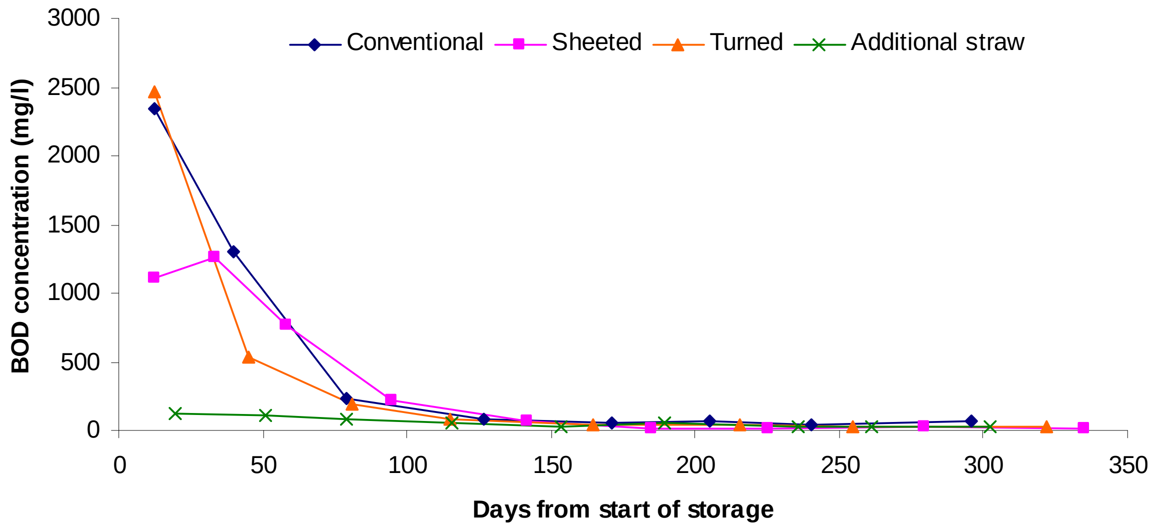


Figure 35: Leachate BOD concentrations from pig FYM stored at ADAS Gleadthorpe for (a) 6 and (b) 12-months (Defra project WA0716)

In contrast to the pig FYM heaps, leachate BOD concentrations from broiler litter heaps (Defra project WA0716) remained relatively stable throughout the storage period (Figure 36), with the sheeted treatment generally having the highest BOD concentration (mean value *c.*7000 mg/l) compared with the uncovered treatment (mean value *c.*1000 mg/l).

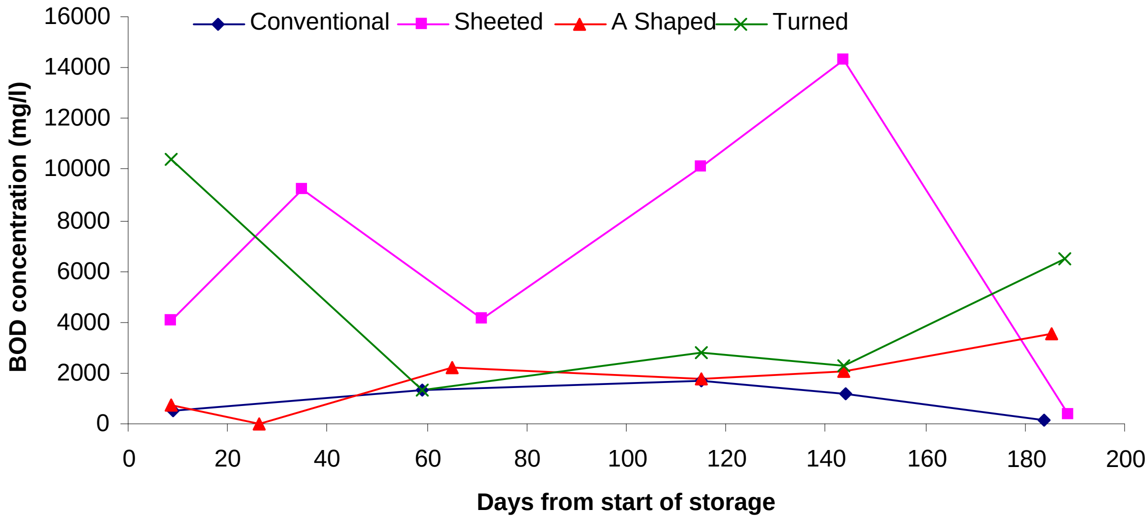


Figure 36: Leachate BOD concentrations from broiler litter stored at ADAS Gleadthorpe for 6-months (Defra project WA0716)

Leachate BOD concentrations from stored layer manures (Defra project WA0651) generally decreased throughout the storage period from over 14,000 mg/l at the start of storage to *c.*7,000 mg/l at the end of storage (Figure 37).

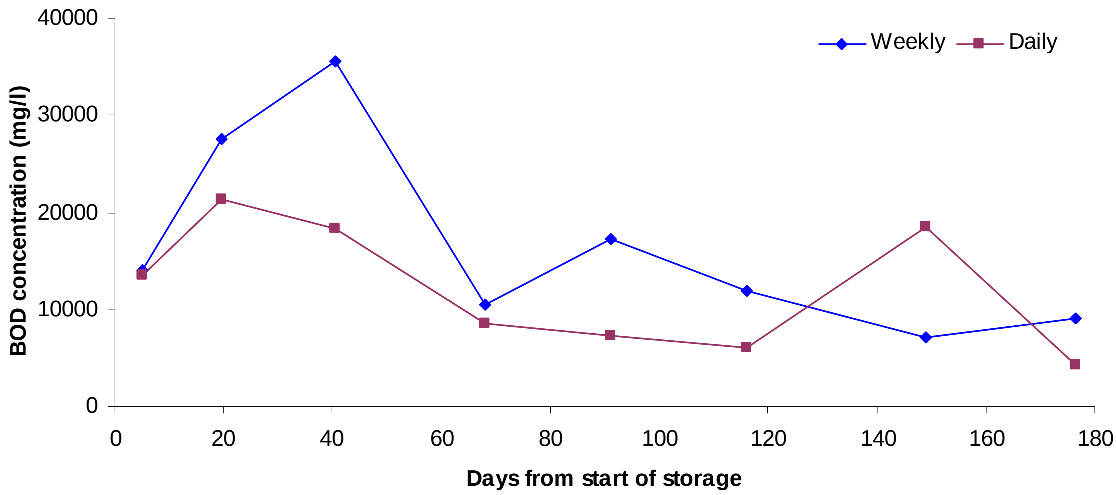


Figure 37: Leachate BOD concentrations from belt-scraped layer manure stored at ADAS Gleadthorpe for 6-months (Defra project WA0651)

10.2 Summary

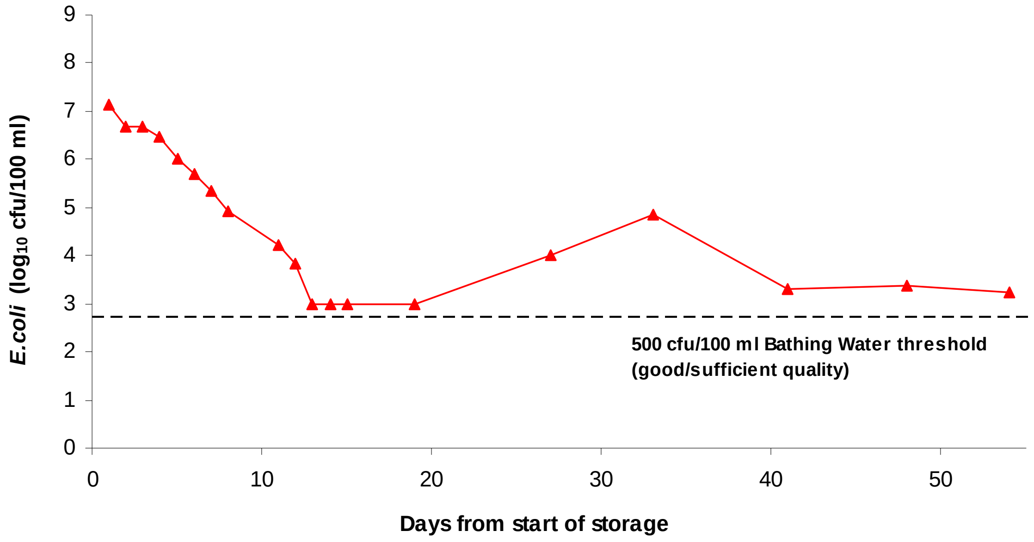
In general, leachate BOD concentrations remained stable or fell over the manure storage period, with peak concentrations typically measured within 2 months of leachate generation. BOD concentrations over 10,000 mg/l were measured in leachates from pig FYM and poultry manure heaps. Overall, the highest leachate BOD concentrations were from layer manure heaps (mean *c.*14,000 mg/l) compared with lower concentrations from pig FYM (mean *c*.1,000 mg/l) and broiler litter heaps (mean *c*.4,000 mg/l). To contextualise these BOD concentrations; pig slurry typically has a BOD level of 20,000–30,000 mg/l, cattle slurry 10,000–20,000 mg/l and dirty water 1,000–5,000 mg/l (MAFF, 1998), whilst treated sewage effluent must typically meet a BOD discharge consent of <20 mg/l before entering a surface water system.

11 FAECAL INDICATOR ORGANISMS

11.1 *E. coli* concentrations

Leachate *E. coli* concentrations (measured as colony forming units – cfu's) from pig FYM heaps stored for 2 months (October to December 2007) and 3 months (March to June 2009) were measured in Defra project WQ0111 at ADAS Gleadthorpe. Leachate *E. coli* concentrations generally decreased during storage from 7-8 $\log_{10}$ cfu/100 ml at the start of storage to *c.*3 $\log_{10}$ cfu/100 ml at the end of storage (Figure 38). *E. coli* concentrations in leachates from the both the pig and cattle FYM heaps were close to or exceeded the Bathing Water Directive (2006/7EC) threshold of 500 cfu/100 ml (2.7 $\log_{10}$ cfu/100 ml) for good/sufficient quality (EU, 2006b).

(a)



(b)

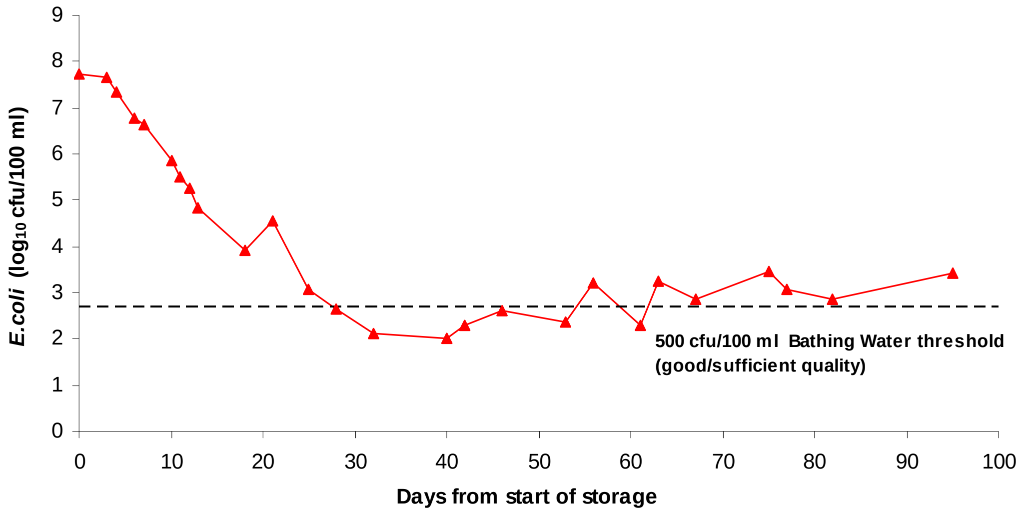


Figure 38: Leachate *E. coli* concentrations from pig FYM stored at ADAS Gleadthorpe for (a) 2 and (b) 3-months (Defra project WQ0111)

E. coli concentrations were also measured in leachates from cattle FYM stored for 3 months (September to December 2008) at ADAS Gleadthorpe. *E. coli* concentrations decreased from 7-8 log_{10} cfu/100 ml at the start of storage to *c.*3 log_{10} cfu/100 ml at the end of the storage period (Figure 39).

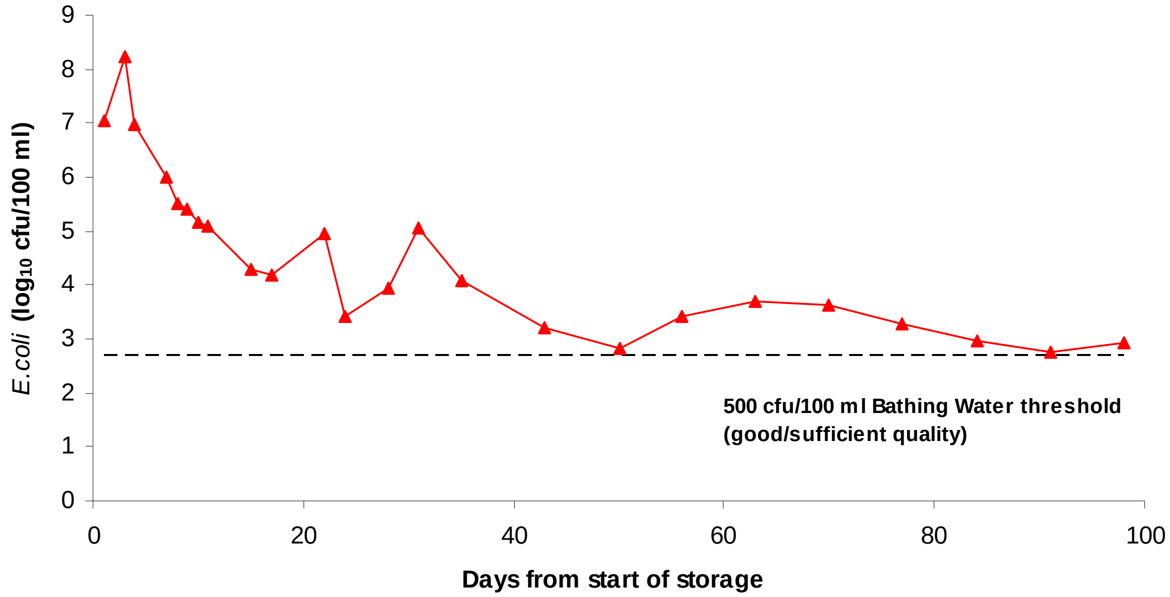


Figure 39: Leachates *E. coli* concentrations from cattle FYM stored at ADAS Gleadthorpe for 3-months (Defra project WQ0111)

11.2 Summary

Leachate *E.coli* concentrations from pig and cattle FYM heaps were highest at the start of storage (7-8 log_{10} cfu/100 ml) and decreased during the first 2-4 weeks of storage to *c.*3 log_{10} cfu/100 ml. *E.coli* concentrations were generally close to or above the Bathing Water Directive threshold (500 cfu/100 ml for good/sufficient quality).

12 SUMMARY OF FINDINGS

General

- Relatively few studies have been undertaken measuring leachate losses from solid manure heaps; for most studies the main focus of the research was on gaseous emissions (i.e. ammonia and nitrous oxide), with any leachate measurements being an ‘add-on’.
- Most information in the published scientific literature was from cattle FYM (or ‘deep litter’ as it is commonly referred to in other Member States). In contrast, the experimental evidence reviewed from recent Defra-funded studies was mainly from pig FYM and poultry manures.
- All of the studies were with manure heaps stored on concrete (or other impermeable surfaces) to facilitate leachate collection (i.e. they were *not* field heaps on a soil base). Moreover, many of the experimental heaps were smaller in size than those typically found on-farm.

Leachate volumes

- There was an inverse relationship ($P<0.01$) between the initial dry matter content of the poultry manures/pig FYM and the overall volume of leachate generated over the storage period (expressed as a percentage of rainfall volumes). As the dry matter content of the manures increased the volume of leachate produced decreased, which was probably because the drier manure heaps were able to ‘absorb’ more of the rainfall (which was subsequently evaporated) rather than contributing to leachate volumes.
- Lower leachate volumes were measured from covered than uncovered poultry manure heaps (*c*.85%), indicating that covering poultry manure fields was an effective method of reducing leachate losses.

Nitrogen

- In general, leachate total N and ammonium-N concentrations (and losses) from both pig FYM and poultry manure heaps were highest at the start of storage (i.e. in the first month of leachate generation) and decreased over the storage period.
- Nitrate-N concentrations (and losses) from poultry manure heaps also decreased over the storage period, however, concentrations (and losses) from pig FYM heaps increased over the storage period.
- Leachate ammonium-N concentrations were consistently higher than the limit value of 0.78 mg/l ammonium-N set in the Freshwater Fish Directive, with values >1,000 mg/l commonly measured. Similarly, nitrate-N concentrations often exceeded the Nitrate Directive limit (11.3 mg/l), with concentrations >100 mg/l commonly measured.

- Total leachate N losses were generally low ranging from 0.8–5.3% of total N into store from uncovered pig FYM heaps and 0.4–8.2% of total N into store from uncovered poultry manure heaps.

Phosphorus and potassium

- There were no consistent patterns in leachate P concentrations (and losses) from the pig FYM and poultry manure heaps. Total leachate P losses were in the range 3.0–12.5% of total P inputs into store from uncovered pig FYM heaps, and 0.03–0.4% from uncovered poultry manures heaps. Covering poultry manure heaps reduced leachate P losses by around 8-fold.
- There were no clear patterns in leachate total K concentrations (and losses) from pig FYM and poultry manure heaps. Total K losses from uncovered pig FYM heaps (range 13.4–37.0% of K inputs) were substantially greater than from uncovered poultry manure heaps (1.0–3.0%). Covering poultry manure heaps decreased leachate K losses by around 9-fold.

Biochemical oxygen demand

- In general, BOD concentrations fell over the manure storage period, with peak concentrations in the range 1,000–20,000 mg/l measured within 2 months of leachate generation. The highest BOD concentrations were measured in layer manure heap leachates (mean *c*.14,000 mg/l) compared with lower concentrations in broiler litter (mean *c*.4,000 mg/l) and pig FYM (mean *c*.1,000 mg/l) leachates.

Faecal indicator organisms

- *E.coli* concentrations in leachates from pig and cattle FYM heaps were highest at the start of storage and decreased rapidly during the first 2-4 weeks of storage.
- Leachate *E.coli* concentrations were generally close to or above the Bathing Water Directive threshold (500 cfu/100 ml) for good/sufficient quality.

13 CONCLUSIONS AND RECOMMENDATIONS

The NVZ-AP (SI, 2008) contains the following rules which control the location of field heaps to minimise the risks of pollutant losses to the environment, viz:

- Field heaps must not be located:
  - within 10m of a surface water or land drain;
  - within 50m of a spring, well or borehole;
  - on land likely to become waterlogged;
  - on land likely to flood; or
  - in any single position for more than 12 successive months (and there must be a two year gap before returning to the same site).
- Poultry manure without bedding/litter which is stored in a field heap must be covered with an impermeable sheet.

13.1 Location of field heaps

The findings of this report have shown that leachates from solid manure heaps can contain *elevated concentrations* of multiple pollutants (e.g. ammonium-N, nitrate-N, phosphorus, BOD and FIOs), which could cause detrimental effects if they reached surface water bodies in an undiluted form.

In practice, pollutants in leachate infiltrating soil underneath a field heap (and in run-off from the heaps) are likely to be either retained in the soil or diluted with 'uncontaminated' water from the rest of the field. Thus, pollutant concentrations will be reduced provided that there are sufficient 'barriers' between the field heap and the receiving water, with distance and slope and the presence of field drains being important influencing factors. There was insufficient evidence from this study to suggest an appropriate distance between the field heap and water bodies to ensure that elevated concentrations of pollutants do not enter surface water bodies; as all previous work was undertaken with heaps stored on concrete (or other impermeable surfaces) to facilitate leachate collection. Based on ADAS' practical field experience, we believe that the present NVZ rules of not storing field heaps within 10m of a surface water or any effective land drain (and not just open field drains or drains backfilled to the surface with permeable material such as stone/aggregate) provide an effective barrier in minimising direct leachate pollution from field heaps.

We conclude:

The 'key' management practice in minimising the risk of leachate from solid manure heaps entering water courses is to ensure that there are sufficient 'barriers' between the field heap and receiving water.

13.2 Storage time

Leachate concentrations of most pollutants (in particular ammonium-N, BOD and FIOs) peaked at start of the storage period (i.e. in the first 2 months of leachate generation) and decreased thereafter. However, elevated leachate P concentrations (from all manure types) and elevated BOD concentrations (from poultry manures) were measured throughout the whole storage period.

No information was available on the potential accumulation of pollutants in the soil underneath field heaps, and their subsequent release; as all previous work was undertaken with heaps stored on concrete (or other impermeable surfaces) to facilitate leachate collection.

We conclude:

Reducing the maximum permitted field heap storage time from 12 months would be of little benefit in reducing ammonium-N, BOD (from FYM) and E. coli losses, but would reduce P and BOD (from poultry manure) losses.

13.3 Covering field heaps

Covering poultry manure heaps (with an impermeable sheet) was shown to be an effective method of decreasing leachate volumes (*c*.85%) and associated nutrient losses.

14 KNOWLEDGE GAPS

We recommend that further research is undertaken to:

- Evaluate the effect of ‘real-world’ field heap manure storage on surface water quality and soil nutrient status, taking into consideration the location of field drains and length of the storage period.
- Gather sufficient evidence to establish if 10 metres is a ‘safe’ distance between field heaps and receiving waters (i.e. surface waters and land drains).
- Establish the extent of leachate volume decreases (and associated improvements in leachate quality) that could be achieved through covering FYM heaps.

We recommend that further industry intelligence is gathered to:

- Assess the likely impact on farming practices of reducing the maximum permitted field heap storage period in Britain from 12 months (to say 6 or 9 months), drawing upon available Farm Practice Survey data etc.

15 ACKNOWLEDGEMENTS

We thank North Wyke Research for kindly supplying their data from Defra projects WA0632 and WA0716.

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